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SINGLE TREE LEVEL SIMULATOR FOR LITHUANIAN PINE FORESTS

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Declaration

I hereby certify that this thesis entitled **"Single tree level simulator for Lithuanian pine forests"** is my own work and it has not been submitted anywhere else for the award of any other academic degree. All information sources that have been used are clearly acknowledged in the text.

Tharandt 30 07 2014

Edgaras Linkevičius

I dedicate this doctoral dissertation to my parents Regina Linkevičienė and Alvydas Linkevičius, my sister Inga Linkevičiūtė and my sweetheart Daiva Kreivaitytė.

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Edgaras Linkevičius

TABLE OF CONTENTS

FIGURES

TABLES

APPENDICES

ACRONYMS AND ABBREVIATIONS

NFI	National Forest Inventory
PEPs	Permanent experimental plots
STLS	Single tree level simulator
VP	Validation plots

Tree level acronyms and abbreviations

ba	Tree basal area [cm^2]
BAF	Diameter and basal area factor
bal	Basal area of larger trees [cm^2]
CC_{66}	Canopy closure at 66% of total tree height [m^2]
CI	Competition index
CI_1, CI_2,	Distance independent competition indices
CI_3...CI_8	Distance dependent competition indices
CIs	Competition indices
cl	Crown length in m
$cl_{relative}$	Relative crown length in m
cr	Crown ratio %
cr_{rad}	Crown radius in m
csa	Crown surface area [m^2]
cv	Crown volume [m^2]
cw	Crown width in m
d_{bh}	Tree diameter at breast height in cm
dist	Distance from the centre of subplot to the subject tree in m
F	Tree vitality indicating value
h	Tree height in m
h_{ca}	Tree horizontal crown area [m^2]
h_{cb}	Tree height to crown base in m
HCB 80	Competitor selection method height to crown base with opening angle of 80 degrees
HWCW	Height of greatest crown width in 66% of subject tree height in m
HWCW 60	Competitor selection method height to widest crown width with opening angle 60 degrees
$i_{\bar{d}}$	Mean values of periodic mean annual tree diameter increment in cm
$i_{\bar{h}}$	Mean values of periodic mean annual tree height increment in m
i_{ba}	Periodic mean annual tree basal area increment [cm^2]
i_{ba_5}	Periodic mean five year basal area increment [m^2]
i_{ba_p}	Periodic mean annual tree basal area increment in previous inventory period [cm^2]
i_d	Periodic mean annual tree diameter increment in cm
i_{d_5}	Periodic mean five year diameter increment in m
i_{d_p}	Periodic mean annual tree diameter increment in previous inventory period in cm
i_h	Periodic mean annual tree height increment in m
i_{h_5}	Periodic mean five year height increment in m
i_{h_p}	Periodic mean annual tree height increment in previous inventory period in m

$i_{h_{rel}}$	Relative tree height increment
inv	Inventory year
p	Time between inventories in years
q	Tree growth area [m^2]
SB 60	Competitor selection method stem base with opening angle 60 degrees
t	Time of observation in years
v	Tree stem volume [m^3]
v_{ca}	Vertical crown area [m^2]
$x_{observed}$	Observed values
$x_{simulated}$	Values of simulation runs

Stand level acronyms and abbreviations

$\bar{CW}$	Mean arithmetic crown width in m
$\bar{D}$	Mean arithmetic diameter in cm
$\bar{H}$	Mean arithmetic height in m
$\bar{HCB}$	Mean arithmetic height to crown base in m
BA	Basal area of remaining stand [m^2]
BAL	Competition index, based on basal area of larger trees [cm^2]
$BA_{removed}$	Basal area of removed stand [m^2]
CAI_v	Current annual volume increment [m^3 ha^{-1}]
CCF	Crown competitor factor %
CI_{stand}	Stand level competition index
D_{100}	Mean diameter of 100 largest trees per hectare or stand top diameter in cm
$D_{100\ AB}$	Stand top diameter (H_{100}) in age 100 years in m
D_{AB}	Site productivity index according to the quadratic mean diameter at base age (100 years) in cm
D_q	Quadratic mean diameter of remaining stand in cm
$D_{q\ removed}$	Quadratic mean diameter of removed stand in cm
GY	Gross volume yield [m^3 ha^{-1}]
H_{100}	Mean height of 100 largest trees per ha or stand top height in m
$H_{100\ AB}$	Stand top height (H_{100}) at base age (100 years) in m
$H_{100(t)}$	Stand top height in the beginning of simulation period in m
$H_{100(t+p)}$	Stand top height in the end of simulation period in m
H_{AB}	Site productivity index according to the mean stand height at base age (100 years) in m
H_q	Mean stand height of remaining stand in m
$H_{q\ removed}$	Mean height of removed stand in m
i_D	Mean annual over the bark stand diameter increment in cm
$i_{H_{rel\ pot}}$	Relative potential stand top height increment
K	Number of trees per plot
MAI_v	Mean annual volume increment [m^3 ha^{-1}]
MSA	Mean stand age in years
N	Number of growing trees ha^{-1}
$N_{normative}$	Normative stand density trees ha^{-1}
$N_{removed}$	Number of self-thinned trees ha^{-1}
NTM	Natural tree mortality
$PAI_{removed}$	Percentage of self-thinned trees from periodic annual volume increment %
PAI_V	Periodic annual volume increment [m^3 ha^{-1}]
SL	Stocking level

S_{plot}	Size of the plot in ha
V	Standing volume [m^3 ha^{-1}]
$V_{removed}$	Volume of removed stand [m^3 ha^{-1}]
ZD_q	Quadratic mean diameter increment in cm

Statistical acronyms and abbreviations

$\bar{X}$	Arithmetic mean of independent variable
$\bar{Y}$	Arithmetic mean of dependent variable
$r\bar{e}s$	Arithmetic mean of residuals
$a_0 \ldots a_k$	Regression coefficients
b_N	Gradient of stand density rule proposed by Reineke
CSS	Corrected sum of squares
$\bar{e}$	Bias
$\bar{e}_{\%}$	Relative bias
F_{Fisher}	Fisher's distribution's critical value
k	Number of parameters in regression model
L	Value of maximum likelihood function
ML	Mortality likelihood values %
MR	Equally distributed random values
MRSE	Mean residual sum of squares
MRSS	Mean regression sum of squares
m_x	Accuracy
$m_{x\%}$	Relative accuracy
n	Number of observations
$\bar{X}_{observed}$	Arithmetic mean of observed value
r	Pearson correlation coefficient
R_1^2	Coefficient of determination between analysed and all other independent variables
R^2	Coefficient of determination
R^2_{adj}	Adjusted coefficient of determination
R^2_{CS}	Cox-Snell coefficient of determination
R^2_N	Nagelkerkle's coefficient of determination
res_{ST}	Standardized residuals
ROC	Receiver Operating Characteristic curve
RSS	Residual sum of squares
S	Sample's standard deviation
S^2	Sample's variance
S_{an}	Standard deviation of coefficient a_n
S_e	Precision
$S_{e\%}$	Relative precision
t_{SD}	Two tailed critical value of Student distribution, t_{SD} 0.05 ($\approx$1.96)
VIF	Variance inflation factor statistics for selected variable
W	Wald statistics
X	Independent variable
X^2	value of Pearson's chi square statistics
Y	Dependent variable
δ	Standard deviation of the mean %
ε	Error of the estimate
$\pi(X)$	Conditional probability

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1 INTRODUCTION

1.1 Problem statement

Until the beginning of 20th century many European forests suffered from overexploitation and devastation caused by timber shortages. To solve this problem, many forest areas, as well as former broadleaved forest areas were afforested with conifer tree species, Norway spruce (*picea abies*) and Scots pine (*pinus sylvestris*). Stands that were mainly, homogeneous, single-layered, monocultures that were both productive and commercially valuable were established. However, the ecological environments of these stands suffered from damage caused by high winds, snow, ice, drought, insects, and fungi. Accordingly soil degradation appeared more frequently in the afforested areas than in forests better adapted to local conditions. In order to solve these aforementioned problems and to increase forest biodiversity, forest conversion (the transformation of pure conifer stands to mixed stands mainly by planting broadleaves under conifer canopies) has started since 1980 (DIACI 2006).

SCHRÖDER et al. (2007) point out that for more than two decades, the main objective of forest management and planning in Germany was forest conversion. The planting of broadleaved species, such as European beech (*Fagus sylvatica*), the common oaks (*Quercus petraea* and *Quercus robur*), under conifer canopies has been one of the most effective methods to reduce risks associated with pure even aged stands. But the applicability of traditional yield tables to these stands is limited by intra and interspecific competition, diversity in spatial structure, age and species composition and variety in growth patterns (SCHRÖDER et al. 2007). Among the attempts to solve these limitations has been the recent development of a variety of single tree level simulators (e.g. BWINPro-S, SILVA, MOSES, PROGNAUS).

In Lithuania, during the last few decades, the leading theory in forest management and planning was optimization of forest stand density and the search for maximal productivity at every time point of stand development. Thus, multiple efforts were made in creating stand level models that are highly effective in managing even-aged monocultures of pine or spruce forests. However, in mixed or converted forests, these models would produce remarkable errors.

The National Forest Program (GOVERNMENT OF THE REPUBLIC OF LITHUANIA 2012) up to 2020 requires that the principles of sustainable forest management will be implemented. Thus, it focuses on retaining and increasing national forest resources, assuring rational usage of Lithuanian forests and increasing their productivity. Particular attention is given to retaining and increasing the stability of forest ecosystems. The National Forest Program sets new goals for forest managers that reach much further than maximal productivity.

These goals cannot be reached without appropriate forest management tools that would be capable of predicting the growth and yield of more structured forests. The single tree level simulator (STLS) would be an appropriate solution, and the introduction of this type of model to Lithuania is the main aim for this research project.

The single tree level simulator that the project used as the basis for research was the BWINPro-S developed in 2004 for free State Saxony of Germany (RÖHLE et al. 2004). Growth conditions in Saxony differ from Lithuanian conditions. Thus, growth models used by the simulator have to be re-parameterised according to local Lithuanian growth conditions. However, this study focuses not only on re-parameterisation of BWINPro-S core elements, but parallel attempts to develop original elements like a tree diameter increment model or a natural tree mortality likelihood model.

The single tree level simulator BWINPro-S comprises of three tree core elements: basal area increment model, height increment model and natural tree mortality model (NAGEL et al. 2002)[1]. Since most of single tree forest growth models, such as BWINPro-S, use the competition for growing space that arises between trees to model tree diameter increment, precise assessment and selection for further modelling of competition indices (CIs) and competitor selection methods is another important task for this study.

Re-parameterised BWINPro-S single tree level simulators and newly developed models could be a valuable support for decision makers and forest managers to improve forest management in Lithuania.

[1] In the late 1990s NAGEL (1999) developed and published the simulation programme "BWINPro", which is an important planning tool designed for the prediction of forest growth in the northwestern part of Germany. BWINPro-S" is a derivative version that resulted from a fundamental revision of the programme (RÖHLE et al. 2004) in order to adapt the simulator to the regional-specific growth conditions in Saxony and to extend it by a lot of new components (e.g. implementation of modified competition indices, parameterisation of a new module for the estimation of mortality rates, adaptation to the particular silvicultural requirements in two-storeyed stands, development and implementation of a juvenile growth module for predicting the growth behaviour of advance-planting layers).

1.2 Objectives and tasks

The overall objective for this study was to re-parameterise growth models used in BWINPro-S single tree level simulator (STLS) for Lithuanian pine forests, growing on mineral sites.

Tasks of the study:

1. To create and to evaluate the database required for modelling.
2. To estimate impact of competition for growing space on diameter, basal area and height growth of trees.
3. To develop tree diameter, and re-parameterise basal area and height growth models.
4. To assess natural tree mortality induced by competition between trees for growing space.
5. To develop the first approach of an STLS for pine in Lithuania.

1.3 Hypothesis

1. Site quality is the most important factor that affects forest growth and yield.
2. Distance dependent CIs have higher partial correlation with tree basal area and height increment than distance independent CIs.
3. A re-parameterised model based on Lithuanian data fits better under Lithuanian conditions (regarding diameter, basal area, height increment and mortality).
4. STLS provide valuable support for decision makers and forest managers to improve forest management in Lithuania.

2 SCIENTIFIC BACKGROUND

2.1 Forest management in Europe

The historical evolution of forest management approaches in Europe is divided into three main periods: pre-industrial (up to 19th century), industrial (19th century) and post-industrial (20th century onwards), (PALETTO et al. 2008). In the pre-industrial period, forests were, for medieval human communities, the source of fruits, nuts, honey, meat and timber. Only in the late 15th century were multi-product forests (based on selective cuttings and uneven-aged stands) replaced by agricultural forests with an increasing proportion of clear cuttings (PALETTO et al. 2008).

Forest management in the industrial period was based on the German classic school of forestry. The objectives of forest management were maximum timber production and maximum economic outcome (PALETTO et al. 2008). Thus conifer plantations were planted, because spruces generated the highest yields in the shortest periods. Forest management began to introduce new practices like cycles of planting, cultivation, harvesting and replanting (DIACI 2006).

However, as a result of this type of forest management, damages caused by storm, snow, ice, drought, insects, fungi and possibly soil degradation were more frequent (SPIECKER et al. 2004). At the end of industrial period, theories of sustained yield arose that focus on the needs of future generations (PALETTO et al. 2008).

At the beginning of the early 20th century, close-to-nature forest management methods were developed by forestry scientists, which started the so called back-to-nature process. Careful consideration of forests as a multi-faceted biological ecosystem emerged. Uneven-aged, mixed stands became an important goal for forest managers (DIACI 2006). The conflicts of World War I and World War II renewed ideas of yield and profit (DIACI 2006). The post-industrial period is characterised by two concepts: sustainable forest management and ecosystem management (PALETTO et al. 2008). Sustainable forest management aims to realize social, economic and ecological forest functions and in contrast to sustained yield doctrine places greater emphasis on trade-offs between timber and non-timber forest values (LUCKERT & WILLIAMSON 2005). Ecosystem management focuses on maintaining the ecological integrity of forest ecosystems and highlights five specific goals: maintaining viable populations, ecosystem representation, maintaining ecological process (natural disturbance regimes), protecting evolutionary potential of species and ecosystems, and accommodating human use in light of the previous four goals (GRUMBINE 1994).

To conclude, forest management history in Europe passed through three important periods: pre-industrial, industrial and post-industrial. The first period is characterised by multi-product forests, the second by high productive conifer plantations and the third by back-to-nature and multipurpose forests (sustainable forest management with equal economic, environmental and social needs of society).

2.2 Forest management, growth and yield studies in Lithuania

In Lithuania, in the second half of 20th century, the leading theory in forest management and planning was normal forests theory that aims to optimize forest stand density and seeks for maximal productivity at every time point of stand development (ANTANAITIS & DELTUVAS 1988). Normal forest theory that came from the German classic school of forestry was broadened by adding multifunctional forestry principles and continuous forest usage principles. All forest management systems were based on forest growth and yield principles and regularities (ANTANAITIS & DELTUVAS 1988). World War II caused Lithuanian forests to be overexploited and over felled (KULIEŠIS et al. 2011). Furthermore, much of the residential and industrial infrastructure of Lithuania was destroyed during the World War II, resulting in large urban rebuilding programmes, which led to a high demand for construction timber in the post-war years.

Forest growth is defined as the volume of all trees that grow in a certain area during a specified duration (one year, ten years or a rotation period) and is equal to the total volume increment in the analysed period (KULIEŠIS 1989a). The total volume increment is calculated as the difference of standing volumes at the beginning and at the end of the inventory period including volumes of self-thinned or removed trees (KULIEŠIS 1999). Additionally, forest yield is determined as the accumulated volume of trees from the time of stand establishment or another specified time (PRETZSCH 2009).

Forest growth and yield studies in Lithuania were started in the beginning of 20th century by Prof. Povilas Matulionis (MATULIONIS 1924) who developed the first forest growth and yield tables for Lithuanian spruce, pine, oak, aspen, black alder and birch stands. For this purpose MATULIONIS (1924) adopted the scientific findings of the Russian forester Vargas de Bedemar and the Prussian scientist from Eberswalde dr. Schwappach 1886-1908. Although the tables were quite simple, Matulionis used classes I to V of the bonitet system to describe stand productivity.

Already, in the second half of 20th century, scientifically based investigations on forest growth and yield had begun in Lithuania, which paid particular attention to the growth and yield of pure even-aged monoculture stands. For example, BUTĖNAS (1968) developed yield tables for pure pine stands that grow on Vacciniosa, Myrtillosa and oxalidosa forest types using classes I to V of the bonitet system. Other scientists (see for example ANTANAITIS 1966) focussed on investigating the peculiarities of diameter and volume increment of monocultures, by applying basal area and volume increment rates. Summarised regularities of forest growth and yield of pure even-aged monoculture stands were presented by ANTANAITIS & ZAGREJEV (1981) and ANTANAITIS et al. (1986).

The other crucial field of research for Lithuanian forestry was the formation of maximally productive pure forest stands. KAIRIŪKŠTIS & JUODVALKIS (1985) prepared the reference of the most productive models for the main tree species in Lithuania. KAIRIŪKŠTIS et al. (1979), KAIRIŪKŠTIS & JUODVALKIS (1985), KAIRIŪKŠTIS et al. (1997) and JUODVALKIS & KAIRIŪKŠTIS (2009) analysed the impact of intermediate cuttings for individual tree and stand growth and prepared a reference of the most optimal thinning regimes. KAIRIŪKŠTIS & JUODVALKIS (1985) developed models not only for pure but also for mixed stands.

Critical studies on yields that summarised previous research were conducted by KULIEŠIS (1989, 1993). After analysing growth and yield of monocultures in Lithuania, KULIEŠIS (1989a) defined the most important forest formation types as follows: accelerated formation stands (stands with possible maximum initial basal area), normal formation stands (stands with optimal initial basal area) and stands of slowed formation (stands with very low initial basal area). Finally, KULIEŠIS (1993) presented summarised forest yield models for pure even-aged stands in Lithuania based on the generalized peculiarities of mean stand height, quadratic mean diameter, increment of mean diameter, form factor, self-thinning of trees, as well as by a balance between the main parameters of the living and removal parts of a stand. Between 1997 and 2000, PETRAUSKAS & KULIEŠIS (2004) used KULIEŠIS' (1993) models to develop a large scale scenario simulator KUPOLIS that enables researchers and forest managers to evaluate regimes of stand treatments and to clarify sustainable use alternatives.

In 1992, Lithuania signed the Rio de Janeiro convention on biological diversity. The Lithuanian parliament ratified it in 1995 (PARLIAMENT OF THE REPUBLIC OF LITHUANIA1995), which led to Lithuania's forest management to take into account the theory of sustainable development (GOVERNMENT OF THE REPUBLIC OF LITHUANIA 2012).

To conclude, the effect of the major historical event in the first half of the 20th century, World War II, on Lithuania's residential and urban infrastructure shaped the management practices of Lithuanian forestry during the ensuing post-industrial period. The leading forest management theory in Lithuania till the end of the 20th century consisted of the theory of normal forests enlarged by additional principles of multipurpose and continuous forest usage. After the ratification of the Rio de Janeiro convention on Biological Diversity in 1995, the principles of sustainable development were introduced.

2.3 Factors that affect forest growth and yield

The most important factors that affect forest growth and yield are climatic conditions, genetic material, potential site productivity, tree age, stand structure and silvicultural treatments (ASSMANN 1970, ANTANAITIS & ZAGREJEV 1981, GRIGALIŪNAS 1997, PRETSCH 2009, JUODVALKIS & KAIRIŪKŠTIS 2009).

Climatic conditions are defined by availability of light (photosynthetically active radiation), temperature and precipitation for plant growth (KARAZIJA 2008, KIMMINS 2004). Europe comprises five eco-climatic zones: polar tundra, boreal, temperate, arid and subtropical (BARNES et al. 1997). Lithuania is located in the northern part of the temperate climatic zone. Even though the west of Lithuania lies on the shores of the Baltic Sea, the climate is not typically maritime, as continentality increases from the west through to the east. Continentality increases the variation of mean annual and daily temperatures, the weather becomes drier and results in decreases in the amount of annual precipitation (BUKANTIS 1994). The temperature of summer months (July, August) as well as the temperatures of late winter and early spring comprise a major factor influencing the growth of Scots pine Lithuania's geographic latitudes (JUKNYS et al. 2002). By contrast, monthly precipitation is a minor factor influencing the growth of the same species of pines in Lithuania, with precipitation in June being considered to be the most important (JUKNYS et al. 2003, AUGUSTAITIS & BYTNEROWICZ 2008).

Genetic material. The provenance of tree species affects both gross yield produced and wood quality. PRESCHER & STAHL (1986) report of trees grown in the same location that while trees from southern provenances have superior growth over trees from northern provenances, the former grew less straight than the latter. STAHL et al. (1990) found a similar impact of provenance on wood quality and formulated a quite similar conclusion that transfer of provenances to the south decreased the appearance of spike knots and increased the number of straight stems per hectare. JANSONS & BAUMANIS (2005) found that the average yields of trees with the southern provenances of eastern Germany (DE) and Poland (PL) were higher than the average yields of trees from the northern provenance of Latvia (LV). For example, the yield of trees grown in: (1) Liepāja, on the west coast of LV were proportionately smaller than DE by 17% and PL by 19%; (2) in Zvirgzde, on the eastern border of LV were proportionately smaller than DE by 3% and PL by 23%; and (3) Kalsnava, central LV were proportionately greater than DE by 19% and smaller than PL by 4%. However, in comparison to LV trees of stem straightness, trees were considerably more crooked in DE (31-41%), and PL (12-25%), and in comparison of branchiness, PL trees were 6-15% poorer than DE trees. Results from Lithuanian trials showed no clear genetic differentiation of populations except for diameter, although marked latitudinal transfer effect and indistinct longitudinal transfer were reported and that populations of southern provenance had superior growth compared to northern provenance (ABRAITIS & ERIKSSON 1996, 1998).

Potential site productivity. "Site productivity is a quantitative estimate of the potential of a site to produce plant biomass, and embraces two concepts: the site potential and that part of the site potential realized by a given forest stand" (SKOVSGAARD & VANCLAY 2008). ASSMANN (1970) argues mean stand height of a particular age appeared to be very suitable measure of site quality, and points out that the entire range of mean stand height values over the age are simply divided by certain range and for each range the mean curves are drawn. BAUR (1877) constructed the first yield tables, in which site classification was based on stand height. Following this concept, EICHHORN (1902) developed his renowned rule which states that "total volume production of a given tree species at a given stand height should be identical for all site classes". However, ASSMANN (1970) found that even with the same age and mean stand height total volume yields of forest stands vary about 15% depending on site conditions and sub-divided Norway spruce yield tables into three yield levels: low, medium and high. Further research shows that potential stand productivity may be affected by silvicultural treatments (ASSMANN 1970, KAIRIŪKŠTIS et al. 1979, KAIRIŪKŠTIS & JUODVALKIS 1985, KULIEŠIS 1989a, KULIEŠIS & SALADIS 1998, KAIRIŪKŠTIS & JUODVALKIS 2005, SKOVSGAARD & VANCLAY 2008, JUODVALKIS & KAIRIŪKŠTIS 2009, PRETZSCH 2009).

Tree age. Tree age impacts tree height, diameter at breast height, volume growth and volume increment (ASSMANN 1970, ANTANAITIS & ZAGREJEV 1981). Thus, mean stand age (MSA) impacts both volume growth and yield of a stand (ANTANAITIS et al. 1986).

The standing volume yield curve exponentially increases over MSA. By contrast, the curves of current annual volume increment (CAI_v) and mean annual volume increment (MAI_v)

increases over MSA, reach the culmination points and then exponentially decrease (ANTANAITIS & ZAGREJEV 1981). The culmination point of CAI_v and the inflection point of the yield curve intersect after approximately 20 years. MAI_v culminates later than CAI_v, intersecting with CAI_v at approximately 40 years (ANTANAITIS et al. 1986). In other words, growth of trees increases for 20 years, reaches maximum and then exponentially decreases. Research has established a similar relationship between tree height and tree age, tree diameter at breast height and tree age as well as tree stem volume and tree age (ASSMANN 1970, ANTANAITIS & ZAGREJEV 1981, PRETZSCH 2009).

This study refers to four distinct tree age periods for Lithuanian pines, for which KARAZIJA (2008: 48) gives age ranges: young (1-40 years), middle aged (41-80 years), pre-mature (81-100 years) and mature (101-140 years). Henceforth these four age periods are, respectively, abbreviated to $Y^{1\text{-}40}$age, $Mid^{41\text{-}80}$age, $Prem^{81\text{-}100}$age and $Mat^{101\text{-}140}$age when referring to either individual trees or stands.

Stand structure. PRETZSCH (2009) comprehensively describes stand structural features that impact tree growth and lists them as follows: horizontal tree distribution pattern, stand density, tree size differentiation, structural and species diversity and tree species intermingling. PRETZSCH (2009) contends horizontal tree distribution could be random (typical for virgin, almost natural, mixed forests) regular or clumped (typical for artificially regenerated forests). EKÖ & AGESTAM (1994) state that naturally regenerated stands produce a superior quality of wood to planted stands, however the volume yield production during a rotation was found to be 20% less in naturally regenerated stands. These findings are supported by AGESTAM & EKÖ (1998), who state that better quality parameters (the percentage of straight trees, the number of branches per whorl, the mean diameter of the thickest branches below two metres) were found in naturally regenerated stands rather than in planted stands, however, planted stands were slightly more productive. GRADECKAS & MALINAUSKAS (2005), on various site types in Lithuania, show that the productivity of 40 year old planted pine stands was higher by 39-40% compared to naturally regenerated stands and that the productivity of 80 year old planted stands compared to naturally regenerated was 21-28% higher.

Tree size differentiation is another crucial productivity factor. ASSMANN (1970) concludes that trees of dominating classes (Kraft 1 and 2) not only produced the major proportion (85-95%) of the increment of $Mid^{41\text{-}80}$age even to heavily thinned stands, but equally they reached a higher level of productivity. KAIRIŪKŠTIS et al. (1979) states that if productivity of A class

(Kraft II class) would be equal to 100%, then productivity of A^1 class (Kraft I class) in Y^{1-40}age stands would be 110-95% and in $Mat^{101-140}$age stands 90-100%. Productivity of B class (Kraft III class) trees would at Y^{1-40}age be 80-50% and during $Mat^{101-140}$age 50-90%. Productivity of C class (Kraft IV) class trees never reaches more than 20-30%. Due to the positive change in class structure resulting from thinning and intermediate felling (i.e. leaving A class (Kraft I) trees), a pure additional increment was noted that could be higher by 12% as compared to felling of the same intensity occurring without changing class structure of trees (KAIRIŪKŠTIS & JUODVALKIS 2005). These findings concur with topic related research since the 1970s (KAIRIŪKŠTIS, 1973; KAIRIŪKŠTIS & JUODVALKIS, 1985; OZOLINČIUS, 1996; KAIRIŪKŠTIS et al., 1997; LOCKOW, 2003 and JUODVALKIS & KAIRIŪKŠTIS, 2009).

Structural and species diversity concerns such issues like productivity of pure and mixed stands and intermingling of species take into account the distribution of tree species inside the mixtures (PRETZSCH 2009). Researchers have analysed productivity of pure and mixed stands, however various authors report contrasting results. ASSMANN (1970), PUKKALA et al. (1994b) and JONSSON (2001) found that volume production in pine and spruce mixtures could be up to 20% more productive compared to even aged pure spruce or pine stands. However, FRIVOLD & FRANK (2002), LINDEN & AGESTAM (2003) and AGESTAM et al. (2006) while comparing the growth of spruce and pine mixtures with spruce and pine monocultures did not find significant differences between them. In Lithuania, MALINAUSKAS (1978) provides evidence that spruce and pine mixtures with a pine proportion of 20-30% on productive sites were 17% more productive than pure spruce stands. However, TEBĖRA (1978) concludes that a 10% birch mixture in pine stands decreases productivity of stand by 7-8%. PRETZSCH & BIBER (2010) conclude that the effects of a mixture of trees may be both positive and negative. The right combinations of early and late successional species, ontogenetically early and late culminating species, or shade intolerant and shade-tolerant tree species could increase productivity by as much as 30%. By contrast, if ecological niches and functional characteristics are similar, species may compete for the same resources, and productivity could be reduced by 20%.

Silvicultural treatments. Forest management and science has since the 17th century discussed whether or not the volume increment of trees, growing and gross yields of the stands may be improved by silvicultural treatments, mainly by regulating stand density. A common belief in the middle of the 17th century was that untreated stands were the most productive, and any reduction in density would cause growth losses (ROUSSEAU 1762). However, experiments conducted in the first decade of the 20th century (SCHWAPPACH, 1908 and SCHIFFEL, 1904) show that the growth and productivity of young spruce stands increase after intensive thinning. Results of later experimental research both support as well as contradict these findings.

ASSMANN (1970) bases his optimal stand theory on maximum (maximum basal area over the period), optimal (highest possible increment that might be achieved) and critical (95% of the potential maximum increment for a site can be achieved) basal area of stand. Assmann (1970) contends maximum volume increment in 42-51 year old spruce stands is reached when the basal area of the stand is equal to 75% of the maximal basal area. In 51-61 year old stands, the optimal basal area increases up to 90-95%. So with increasing age the intensity of thinning should decrease. The favourable effect of thinning on volume has received a great deal of attention (HAMILTON, 1976; ANTANAITIS & ZAGREJEV, 1981; ANTANAITIS et al., 1986; KULIEŠIS, 1997b; KULIEŠIS & SALADIS, 1998; PELTOLA et al., 2007 and PRETZSCH, 2009).

Equally, a good deal of research experiments (from 30 to 100 years in duration) indicate that thinning has negative effect to stand productivity, in which total volume production and volume increment of stands were the most frequent for the non-thinned control treatments (see for example HAMILTON, 1981; CURTIS et al., 1997; MÄKINEN & ISOMÄKI, 2004; SKOVSGAARD, 2009and NILSSON et al., 2010). Additionally, wood quality decreases significantly with increasing thinning intensity (PRESCHER & STAHL 1986, STAHL et al. 1990, PERSSON et al. 1995, MALINAUSKAS 1999, KAIRIŪKŠTIS & MALINAUSKAS 2001). Within Lithuania, optimal thinning intensity is a frequent research topic (KAIRIŪKŠTIS 1973, KAIRIŪKŠTIS et al. 1979, KAIRIŪKŠTIS & JUODVALKIS 1985, KAIRIŪKŠTIS et al. 1997, KAIRIŪKŠTIS & JUODVALKIS 2005 and JUODVALKIS & KAIRIŪKŠTIS 2009. The consensus is the maximum thinning effect can only be reached with optimal thinning intensity that appears in 20 year old stands at 12-20% of growing volume and in 50 year old stands at 5-9% of growing volume.

To conclude, forest productivity is a complex issue, influenced by various factors. Climatic conditions - temperature and precipitation - are critical factors limiting tree growth. Genetic material predefines the growth intensity and wood quality of trees. Site productivity predefines the potential stand productivity. Furthermore, tree growth at $Y^{1\text{-}40}$age increases, reaches the maximum and then with increasing age exponentially decreases. Stand structure can have both a positive and a negative impact on tree growth. Finally, only light silvicultural treatments can increase stand productivity and maintain the required level of quality.

Thus, it is most important that a model is developed for Lithuania that would be able to take into account the most important factors that influence forest growth and yield and would enable to forest management to prepare alternative plans according to predefined forest management goals.

2.4 Modelling in forestry

2.4.1 Forest growth models for ecosystem management: the overview

VANCLAY (1994) states that a model is an abstraction or a simplified representation of some aspect of reality and classifies forest growth models as elements of one of three groups. Firstly, models for prediction (whole stand models, size class models and single tree models); secondly, models for understanding (eco-physiological process models and succession models) and thirdly hybrid models. For a detailed review of forest growth models see PORTE & BARTELINK (2002).

Whole stand models. Whole stand models are used to predict yields in pure even-aged stands (BURKHART & TOME 2012). The development of whole stand models covered the period from the end of the 18th century to the second half of the 20th century. The progress and evolution of whole stand models can be divided into four stages: (i) experience tables of the yield, (ii) standardized yield tables, (iii) computer supported yield table models and (iv) stand growth simulators (PRETZSCH 2009). First generation yield tables were developed mainly in the late 18th and the 19th centuries by PAULSEN (1795), HARTIG (1795), COTTA (1821), PRESSLER (1865, 1870, 1877) and SMALIAN (1837) (all cited in PRETZSCH 2009). These yield tables were characterised by unsatisfactory databases, regional limitations and limited compatibility due to the different methods used (PRETZSCH 2009).

In the end of the 19th century, the Association of German Research Stations decided on the framework for the composition of yield tables and set a basic standard on which a new generation of standardized yield tables could emerge (PRETZSCH 2009), see for example the forest yield tables presented by SCHIFFEL (1904), SCHWAPPACH (1908), MATULIONIS (1924) and WIEDEMANN (1936/1942).

In the second half of the 20th century computer-supported yield table models emerged. These models had, as a core element, a biometric model in the form of a flexible system of mathematical equations, which could be parameterised using data from study sites (ASSMANN & FRANZ 1963, VUOKILA 1966). In the Lithuanian context, ANTANAITIS (1966), BUTĖNAS

(1968), REPŠYS et al. (1983) and KULIEŠIS (1993) all contributed significantly to the development of these type of yield tables and models.

The fourth generation stand growth simulators are shaped as computer programs that are capable of predicting stand development under a variety of site conditions for different initial stem numbers and management regimes (PRETZSCH 2009). In Lithuania, the yield model developed by KULIEŠIS (1993) formed the basis of the stand growth simulator model KUPOLIS, which is able to predict the dynamics of forests resources under different forest management, economic and environmental conditions (PETRAUSKAS & KULIEŠIS 2004).

PENG (2000) argues that whole stand models have some important shortcomings. Yield tables do not provide any size-class information needed to evaluate various utilization options and cannot be used to analyse a wide range of stand silvicultural treatments.

Size class models. Size-class models for even-aged stands generate future diameter distributions (stand tables) according to an initial measured diameter distribution (BURKHART & TOME 2012). Size class models represent a compromise between stand models and individual tree models, since they expand the computational effort of stand models and reduce the level of detail required in a single tree model (GADOW & GANGYING 1999). When only one class exists the method is a whole stand approach and then each tree is considered because the single class method is a single tree approach (VANCLAY 1994).

Size class models are divided into three groups: (i) advanced stand models based on a system of differential equations, (ii) transition matrices and (iii) models based on progressive distributions (VANCLAY 1994, PRETZSCH 2009).

Growth and yield in even-aged stands is simply a function of site quality, stand age and stand density. Stand density is a function of site quality, age and initial density. Indicators of site quality are a function of age (BURKHART & TOME 2012). These functions are some of the elements that comprise the system of differential equations.

Matrix models consist of three parts: a matrix of forest areas that describe the state of the forest; a set of transition probabilities that under different treatments governs the transition of areas between the elements of the matrix, and lastly a set of activities (see SALLNÄS 1990).

Progressive distributions, as PRETZSCH (2009) explains describe a stand according its trees' diameters and height distributions and models the stand's development as a periodic progression of these frequency distributions. For typical examples of progressive distribution models see VANCLAY (1989), HAUHS et al. (1995), GADOW & GANGYING (1999),PENG et al. (2002), NORD-LARSEN & CAO (2006) and PALAHI et al. (2006).

By evaluating size class models, PENG (2000) states that these models require only overall stand values as input, provide detailed size-class information as output, but are insufficiently flexible to evaluate a broad range of stand silvicultural treatments.

Single tree level simulators (STLS) represent a stand as a mosaic of trees and simulate the growth of each single tree (MUNRO 1974). These models represent a much higher level of resolution (NEWNHAM 1964, WYKOFF et al. 1982) that enables researchers to simulate mixed or pure stands of different age and structures, thus providing more flexible possibilities for forest management (PRETZSCH et al. 2002). The STLS comprise two groups: distance dependent, that use actual stem positions and distance independent that do not (MUNRO 1974). Distance independent STLS use crown competitor factor (KRAJICEK et al. 1961) as a quotient that reduces maximum possible diameter increment to certain conditions (ARNEY 1972) or directly estimates competition effects to tree diameter increment. Examples of distance independent models are PROGNOSIS developed by STAGE (1973), STAND PROGNOSIS MODEL developed by WYKOFF et al. (1982), and PROGNAUS developed by MONSERUD & STERBA (1996), STERBA & MONSERUD (1997), and STERBA et al. (2002).

Newnham (1964) developed the first distance dependent approach that used potential tree diameter growth and then reduced it to a particular status by applying competition index (CI). EK & DUDEK (1980) in a review of forest modelling state that up to 1980 the majority of forest growth models were based on this approach, see for example HEGYI (1974) and DANIELS et al. (1979). Various modellers have, since 1980, continued to use the distant dependent approach, such as WENSEL et al. (1987), DANIELS & BURKHART (1988), and specific models like PTAEDA2 (BURKHART et al. 1987), MOSES (HASENAUER 1994), and SILVA, (PRETZSCH 1992, PRETZSCH 2002, PRETZSCH et al. 2002).

Parallel to approaches that predict potential tree growth according to modifiers, an approach has been developed that uses distance dependent competition indices (CIs) to estimate competition effects to tree diameter increment, STAND model, (PUKKALA 1987, PUKKALA et al. 1994a, PUKKALA et al. 1994b, PUKKALA et al. 1998), and BWINPro model, (NAGEL 1999, DÖBBELER et al. 2007).

Individual tree models provide maximum detail and flexibility for evaluating alternative utilization options and stand treatments; however, these models are more expensive to develop and require a more detailed database to implement (PENG 2000).

Eco-physiological process models. Process models are essential scientific tools, providing a framework that connects disparate pieces of information and knowledge (MÄKELÄ et al.

2000). They are based on basic physical, chemical, and eco-physiological relationships and provide information about carbon, nitrogen, and water cycles, supporting comprehensive understanding and management of ecosystems (PRETZSCH 2009).

BARTELINK (2000) developed the process based model COMMIX on three major assumptions: radiation is crucial in growth, the dry matter production of a tree is related to the radiation it absorbs and the partitioning of the dry matter growth over the biomass components is dependent both on tree state and on growing conditions. The same structural patterns are found in the process based model BALANCE, developed by GROTE & PRETZSCH (2002). However, as PRETZSCH et al. (2008) contend, eco-physiological process models have not reached their potential to predict future trends because as “Yet, actual forest yield predictions without guiding empirical functions are not yet very precise”.

Succession models (gap models). Gap models are, as PRETZSCH (2009) explains, used to investigate competition and succession processes in near natural forest stands, to predict long-term succession patterns in unmanaged forest stands and to promote ecological understanding of biomass production during the succession. BUGMANN (2001) in an overview of gap models underlines their four assumptions: (i) the forest stand is abstracted as a composite of many small patches of land with different ages or succession stages, (ii) patches are horizontally homogeneous, with no exact tree positions within the patch, (iii) the leaves of each tree are located in an indefinitely thin layer (disk) at the top of the stem, and (iv) successional processes in each patch are described independently, with no interactions. Typical examples of gap models are JABOWA (BOTKIN et al. 1972), FINNFOR (KELLOMÄKI et al. 1993, KELLOMÄKI & VÄISÄNEN 1997), SORTIE (PACALA et al. 1993, PACALA et al. 1996), and FORSKA-M (LINDNER et al. 1997, LANDSBERG & COOPS 1999).

Gap models also provide output data relevant to forest management like diameter, height and volume development of individual trees or stands, yet, input and output variables are less suited to forest management demands (PRETZSCH 2009).

Hybrid models. MÄKELÄ et al. (2000) states that hybrid models advantageously contain both causal and empirical elements. Hybrid models have, as PRETZSCH (2009) explains, functions that estimate the productivity of biomass and wood volume in relation to primary factors like precipitation, leaf nitrogen content, temperature, and radiation. PENG et al. (2002) argue that while it is almost always possible to find an empirical model that fits better to certain data than process based models, empirical and process models can be joined into hybrid models to avoid to some extent the shortcomings of both approaches. BATTAGLIA & SANDS (1998) state that the needs of potential users of forest models are so various that empirical models can hardly satisfy all of them. PENG (2000) argues that due to the challenges of forest research in the future (predictions of growth and yield, of mixed species, forest responses to environmental changes) the hybrid approach may be useful. A representative hybrid model is TRIPLEX developed by PENG et al. (2002). Yet, hybrid models, as PRETZSCH et al. (2008: 1071) have little practical use, as “neither gap models nor hybrid models have been found reliable enough to reach any practical relevance as management tools”.

To conclude, whole stand models as well as size class models are appropriate to predict yields in pure even-aged stands. STLS are used to simulate the growth of mixed or pure stands of different age and structures. Eco-physiological process models support comprehensive understanding and management of ecosystems. Succession or gap models are used to investigate succession processes and to predict long-term succession patterns. Hybrid models are used for the prediction and understanding of stand development. Taking into account the present status of research in Lithuania, development of STLS is recommended.

2.4.2 Single tree level simulator: the most important modelling features

All STLS comprise three core modular elements: tree growth, ingrowth and regeneration, and mortality (BURKHART & TOME 2012). As an example the structure of BWINPro-S, a distance dependent STLS based on BWINPro (NAGEL 1999), is presented in Figure 2-1.

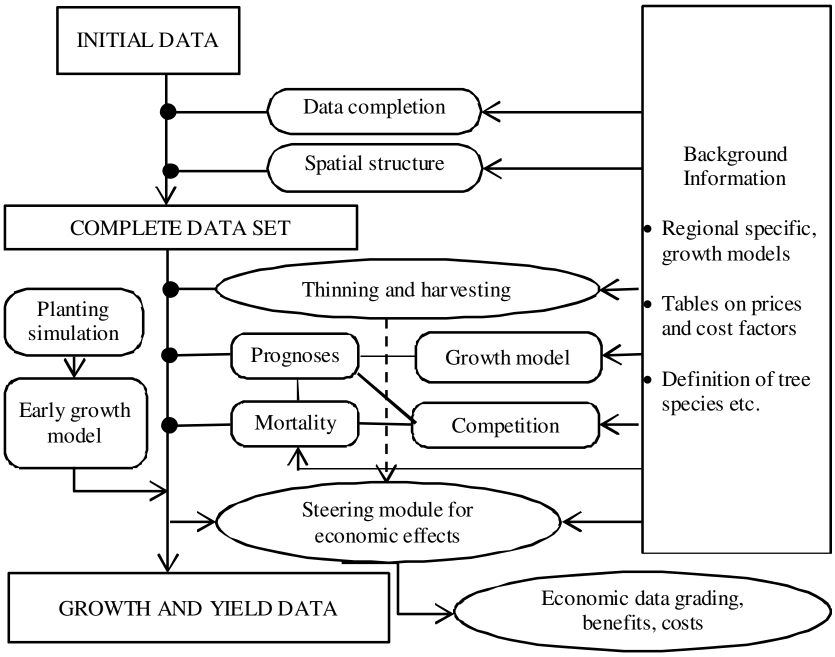


Figure 2-1: The principal structure of BWINPro-S model. Source (RÖHLE et al. 2004).

The simulator consists of four major parts: initial and completed database, program routines, steering module for economic effects and module for presentation of results. The database is completed by applying regional specific functions. The program's routines control the tree growth. Since the program routines are critical for this study, they will be analysed in detail.

NAGEL et al. (2002) explain that initially, those trees that survive till the end of the simulation will be treated separately from those trees that will be cut or self-thinned (based on probabilities of self-thinning). The diameter and height increments of the remaining trees are estimated for the entire simulation period by using predefined formulas. Tree diameter growth and natural tree mortality is controlled by the competitive situation of each tree. The model next calculates new parameters (tree diameter at breast height, tree height, and crown dimensions) for each tree after a certain period of time, which is defined by the duration of the simulation.

In the following subsections, the most appropriate CIs, tree diameter, basal area and height increment as well as natural mortality equations used in STLS will be analysed in more detail. Those defined as the best models will be further evaluated in this study.

2.4.3 The influence of competition for growing space to tree growth

Competition between trees exists when resource (light, water and nutrients) availability falls below the sum requirement of the population for optimal growth (BRAND & MAGNUSSEN 1988). Competition that arises between members of the same species is called intraspecific, and competition that occurs between two different species is named interspecific (KIMMINS 2004). Two-sided competition between individuals exist if competitive effects of smaller and larger individuals in some sense are equal. If larger plants have a competitive advantage over small plants this indicates asymmetric or one-sided competition (WEINER 1990). WICHMANN (2002) states that above-ground competition for light is of asymmetric nature.

The competitive stress of a target tree is estimated by calculating its CIs. “Competition indices quantify the space occupation and spatial constellation of individual trees within a stand and indicate the associated access to resources in one or a few surrogate variables” (PRETZSCH 2009: 334). MUNRO (1974) classifies all CIs to distance independent or distance dependent.

Distance independent CIs are based on simple functions of stand or tree level variables in relation to the average or maximum tree value of the stand and do not require individual tree coordinates (BURKHART & TOME 2012). Most of the distance independent CIs can be grouped to four categories: 1) based on potential crown extension, 2) based on relative size, for example tree diameter at breast height, 3) based on trees larger than subject tree, and 4) based on crown variables evaluated at a certain percentage of crown length. Crown competition factor (CCF) developed by KRAJICEK et al. (1961) serves as the best example for first category indices. The first category is based on CCF, which is the sum of the maximum crown areas (maximum area that could be occupied by the crown of the tree with specified tree diameter at breast height), for all trees in the stand divided by stand area. ARNEY (1972) improved CCF and re-named it as the crown competitor quotient. The second category uses relative size indices, provided for example by GLOVER & HOOL (1979), ALDER (1979) and DANIELS et al. (1986), and estimate the hierarchical position of certain trees within the stand by comparing diameters, heights or crown variables of trees. The third category represents CI basal area of larger trees (BAL) developed by WYKOFF et al. (1982) and modified by SCHRÖDER & GADOW (1999). This CI is the sum of the basal areas of all trees larger than subject tree. In the fourth category, WENSEL et al. (1987) and BIGING & DOBBERTIN (1995) decribed the CI that sums cross sectional areas of all trees in certain height of subject tree (66% of subject tree height) and divides it from stand area.

Distance dependent CIs are those that take relative tree positions into account. Indices are calculated in two steps: competing trees are determined by applying competitor selection methods, then, the strength of competition from each tree is estimated (PRETZSCH 2009).

Selection methods are divided to five groups: 1) Fixed area methods, 2) Influence zone overlap methods, 3) Competition elimination angle methods, 4) Angle count sampling methods, and 5) Vertical search cone methods. The first group's methods can be defined as a circle of the fixed radius around the subject tree (HEGYI 1974, PUKKALA & KOLSTRÖM 1987), or as circle of a multiple of the mean crown radius (LORIMER 1983, CORONA & FERRARA 1989), or a fixed number of the nearest neighbours (SOARES & TOME 1999). The second group's methods are based on maximal zone of influence that is equal to crown dimensions of open grown trees (OPIE 1968, BELLA 1971). The third group's methods defines each neighbour of a subject tree as an active or passive competitor according to the competition elimination sector defined by specific elimination angle (see for example LEE & GADOW 1997). The fourth group's methods identifies the competitors according to their distance, diameter and basal area factor (BAF) that could be equal to 1, 2 or 4 (HAMILTON 1969, DANIELS 1976, GLOVER & HOOL 1979). The fifth group's methods use an inverse search cone that is set at the different heights of subject trees with various opening angles. For example BIGING & DOBBERTIN (1992) set the inverse cone at the stem base, with opening angle 50 and 60 degrees. PRETZSCH (1995) placed the inverse cone at the widest crown width with opening angle base 60 degrees. SCHRÖDER (2004) set the inverse cone at the height of the crown base with opening angle of 80 degrees.

Most of the indices that estimate strength of competition can be placed in three groups: 1) Influence zone overlap, 2) Growing space polygons and 3) Indices based on relative size between subject tree and competitors. Group 1's CIs estimate competition according to the degree to which trees must share its maximal zone of influence with zones of other trees (OPIE 1968, BELLA 1971, EK & MONSERUD 1974). Group 2's CIs are defined as the area of the irregular polygon constructed around the subject tree (MOORE et al. 1973, ADLARD 1974, ALEMDAG 1978, PELZ 1978). Group 3's CIs are based on relative size relations and distances between subject tree and competitors. Whereas, HEGYI (1974) and DANIELS (1976) express relative size by tree diameter at breast height; HEGYI (1974) and BRAATHE (1980) use tree height; HATCH et al. (1975) use exposed crown area; PUKKALA & KOLSTRÖM (1987), ROUVINEN & KUULUVAINEN (1997) and PREVOSTO et al. (2000) use horizontal and vertical angles captured at the subject tree, and finally, BIGING & DOBBERTIN (1992), PRETZSCH (1995) and SCHRÖDER et al. (2007) use crown dimensions like crown volume, crown surface area, tree horizontal and vertical crown areas.

Evaluation of CIs. *Distance independent CIs*. Many researchers were interested if inclusion of tree positions into the competition model would help to increase the models predictive capacity. LORIMER (1983), MARTIN & EK (1984), DANIELS et al. (1986), CORONA & FERRARA (1989), BIGING & DOBBERTIN (1995) and CASTAGNERI et al. (2008) conclude that distance independent CIs in pure stands performed equally as well as distance dependent, and in some cases showed better results. Yet in mixed forests with much more diversity, especially in a clustered structure, distance dependent CIs are much more reliable (STADT et al. 2007, PRETZSCH 2009). The distance independent CI developed by WYKOFF et al. (1982) was positively evaluated by LORIMER (1983) and LEE & GADOW (1997). CASTAGNERI et al. (2008) find the distance independent CI developed by DANIELS et al. (1986) to be superior over more advanced distance dependent CIs.

Distance dependent CIs. The studies of PUKKALA & KOLSTRÖM (1987), BIGING & DOBBERTIN (1992), BACHMANN (1998) and SCHRÖDER (2004) showed the superiority of angle gauge methods over the other selection methods. BIGING & DOBBERTIN (1992) found that the angle gauge method when the inverse cone is set on the stem base with an opening angle 50-60 degrees was superior to other selection methods. BACHMANN (1998) concluded that setting the inverse cone at the height with the largest crown width with an opening angle 60 degrees was the most appropriate formula. SCHRÖDER (2004) proved that angle gauge when the inverse cone is set on the height to crown base with an opening angle 80 degrees is the best formula.

While estimating the strength of competition, DANIELS (1976) found that size ratio index developed by HEGYI (1974) with BAF factor 2.3 performed better than ARNEY (1972) area overlap index and equally as well as EK (1974) index for both tree diameter and height increment. PUKKALA & KOLSTRÖM (1987) qualify Heygi's (1974) CI as one of the best CIs analysed in their study. HOLMES & REED (1991) support these findings by stating that the simple CIs proposed by HEGYI (1974), LORIMER (1983) and DANIELS et al. (1986) had the same or higher correlations with diameter growth than growing space polygons area overlap or root/crown indices in mixed stands.

BIGING & DOBBERTIN (1992) conclude that the inclusion of estimated crown parameters (crown volume, crown surface area or tree horizontal crown area) substantially improves the performance of distance dependent measures. BACHMANN (1998) after evaluating distance dependent CIs found PRETZSCH'S CI (1995) that is based on relative size of horizontal crown area to be the best. SCHRÖDER (2004) analyses distance dependent CIs developed by HEGYI (1974), PRETZSCH (1995), BIGING & DOBBERTIN (1992), BIGING & DOBBERTIN (1995) and SCHRÖDER'S own index (based on vertical crown area) and found slight advantages of light cone selection methods combined with indices based on crown parameters.

To conclude, distance independent CIs developed by HEGYI (1974) and WYKOFF et al. (1982) are appropriate for further analysis. Distance dependent selection methods, based on inverse angle gauge with various opening angles were positively evaluated by previous studies. While estimating the strength of competition, the equations developed by HEGYI (1974), BIGING & DOBBERTIN (1992), PRETZSCH (1995) and SCHRÖDER (2004) were also positively evaluated, and thus will be analysed by this study.

2.4.4 Methods to model tree diameter increment

Tree diameter growth models are divided into two groups: diameter increment models and basal area increment models, which PRETZSCH (2009) then categorises into a further two groups: models based on potential modifier method and models based on direct estimation of individual tree growth method (see Table 2-1).

Most of diameter and basal area increment models based on potential modifier method have exponential type. By contrast, most of diameter and basal area increment models based on direct estimation of individual tree growth method have pseudo linear (due to logarithmic transformations they become linear) form.

Table 2-1: Diameter increment and basal area increment developed since the 1980s.

Diameter increment model		Basal area increment model	
based on potential modifier method	**based on direct estimation method**	**based on potential modifier method**	**based on direct estimation method**
WENSEL et al. 1987 AMATEIS et al. 1989 ZHANG et al. 1997 LEE et al. 2004	WYKOFF et al. 1982 WYKOFF 1986 VANCLAY 1988 VANCLAY 1989 WYKOFF 1990 HANN & LARSEN 1991 VANCLAY 1991a VETTENRANTA 1999 CAO 2000 PALAHÍ et al. 2003 CALAMA & MONTERO 2005	TECK & HILT 1991 QUICKE et al. 1994 PRETZSCH et al. (2002)	RITCHIE & HANN 1985 PUKKALA 1989 DOLPH 1988 MONSERUD & STERBA 1996 HÖKKÄ et al. 1997 NYSTRÖM & KEXI 1997 NAGEL et al. 2002 STERBA et al. 2002 ANDREASSEN & TOMTER 2003 MAILLY et al. 2003 ZHAO et al. 2004 OHNO et al. 2009

The most important characteristic of each model is the ability to explain as much as possible the variation of the dependent variable, and to make reliable predictions. Goodness of fit of each model is well described by the coefficient of determination (R^2). *Pinus sylvestris* diameter increment models based on direct estimation of individual tree growth method were able to explain from 24% (PALAHÍ et al. 2003) to 58% (VETTENRANTA 1999) of diameter increment variation. *Pinus sylvestris* basal area increment models based on potential modifier method managed to explain about 68% of basal area increment variation (PRETZSCH et al. 2002). *Pinus sylvestris* basal area increment models based on direct estimation of individual tree growth method managed to explain from 33.3% (MONSERUD & STERBA 1996) to 78.2% (PUKKALA 1989) basal area increment variation. Basal area increment model developed by SCHRÖDER et al. (2007) managed to explain 53% of basal area increment variation.

KIVISTE (1988) evaluated and summarised the various tree height, tree diameter and volume growth functions, and recommends Yoshida II, Levakovic III and Mitscherlich II nonlinear functions for height, diameter and volume growth modelling, due to their lowest number of approximation errors and biological plausibility. KIVISTE (1988) states that linear, hyperbole, logarithm and parable models showed particularly poor capabilities to model tree growth.

Nevertheless, each model uses a set of independent variables to predict the development of the dependent variable, in this case tree diameter or basal area increment. The most important independent variables (see Table 2-2) used in the aforementioned models can be classified into three groups:, (i) variables that describe tree size (diameter at breast height, basal area and crown dimensions), (ii) mean stand descriptive variables (basal area per stand and quadratic mean diameter) and (iii) variables that describe competitive conditions (see subsection 2.4.3).

Table 2-2: Tree and stand level independent variables, most commonly used in tree diameter and basal area increment models.

Tree level descriptive variables

Diameter at breast height	**Basal area**	**Live crown ratio**	**Crown dimensions**
WYKOFF et al. 1982	PUKKALA 1989	WYKOFF et al. 1982	PRETZSCH et al. 2002
RITCHIE & HANN 1985	HÖKKÄ et al. 1997	RITCHIE & HANN 1985	SCHRÖDER et al. 2007
WYKOFF 1986	ANDREASSEN & TOMTER 2003	WYKOFF 1986	
WENSEL et al. 1987	OHNO et al. 2009	DOLPH 1988	
DOLPH 1988		AMATEIS et al. 1989	
VANCLAY 1988		WYKOFF 1990	
AMATEIS et al. 1989		HANN & LARSEN 1991	
PUKKALA 1989		MONSERUD & STERBA 1996	
WYKOFF 1990		ZHANG et al. 1997	
HANN & LARSEN 1991		VETTENRANTA 1999	
VANCLAY 1991a		STERBA et al. 2002	
TECK & HILT 1991		MAILLY et al. 2003	
QUICKE et al. 1994			
MONSERUD & STERBA 1996			
NYSTRÖM & KEXI 1997			
ZHANG et al. 1997			
VETTENRANTA 1999			
CAO 2000			
STERBA et al. 2002			
MAILLY et al. 2003			
PALAHÍ et al. 2003			
ZHAO et al. 2004			

Stand level descriptive variables

basal area per stand	**quadratic mean diameter**	**site index**
RITCHIE & HANN 1985	AMATEIS et al. 1989	WYKOFF et al. 1982
DOLPH 1988	PUKKALA 1989	RITCHIE & HANN 1985
VANCLAY 1988	NYSTRÖM & KEXI 1997	WYKOFF 1986
PUKKALA 1989	ZHANG et al. 1997	DOLPH 1988
HANN & LARSEN 1991	ANDREASSEN & TOMTER 2003	VANCLAY 1988
VANCLAY 1991a		WYKOFF 1990
QUICKE et al. 1994		HANN & LARSEN 1991
HÖKKÄ et al. 1997		VANCLAY 1991a
NYSTRÖM & KEXI 1997		TECK & HILT 1991
VETTENRANTA 1999		MONSERUD & STERBA 1996
CAO 2000		HÖKKÄ et al. 1997
STERBA et al. 2002		NYSTRÖM & KEXI 1997
ANDREASSEN & TOMTER 2003		PRETZSCH et al. 2002
PALAHÍ et al. 2003		Nagel et al. 2002
ZHAO et al. 2004		STERBA et al. 2002
		ANDREASSEN & TOMTER 2003
		MAILLY et al. 2003
		PALAHÍ et al. 2003
		ZHAO et al. 2004

To sum it up, basal area increment models have a higher predictive capacity than diameter increment models. Models based on the potential modifier method seem to produce more accurate predictions than direct estimation methods. However, the potential modifier method require potential tree growth data. The basal area increment model developed by SCHRÖDER et al. (2007) managed to explain a reasonable proportion of basal area increment variation compared with other models, thus is appropriate for further analysis. To avoid pseudo linearity, it is recommended to develop original nonlinear diameter increment models as well.

2.4.5 Methods to model height increment

Previous studies of height growth focused on the development of site index equations based on age and site productivity (ASSMANN 1970, KULIEŠIS 1993). Yet, the applicability of these functions was limited due to its nature to express reliably only mean heights in the certain stand. To model height growth of subject trees, two main approaches have been used recently. Height increment of trees could be modelled directly by using tree, stand and site independent variables or by calculating its growth potential and adjusting it with a modifier or reduction factor according to tree's competitive status or vigour (BURKHART & TOME 2012). Models developed by STAGE (1973), WYKOFF et al. (1982) and HASENAUER & MONSERUD (1997) could be presented as valuable examples of first approach. STAGE (1973) log linear lodgepole pine height increment model employs tree height, tree diameter and diameter increment as independent variables. WYKOFF et al. (1982) improved STAGE'S (1973) model by adding habitat and species dependent intercepts. HASENAUER & MONSERUD (1997) for their log linear Norway spruce height increment model used, as independent variables, tree size (tree height, tree diameter and crown ratio), competition (CCF and BAL) and site (elevation, slope and aspect). This model was able to explain 44% of height increment variation.

The second modelling approach is more common in the literature. The potential modifier method was used by ARNEY (1972), MITCHELL (1975), KRUMLAND (1982), RITCHIE & HANN (1986), BURKHART et al. (1987), WENSEL et al. (1987), PRETZSCH et al. (2002) and SCHRÖDER et al. (2007). When calculating potential tree growth the independent variable of site quality and age are usually employed. Site quality is expressed as a site index, estimated by the mean stand height. Age is defined as tree age at breast height (ARNEY 1972, MITCHELL 1975, KRUMLAND 1982, WENSEL et al. 1987, PRETZSCH et al. 2002) or MSA (RITCHIE & HANN 1986, BURKHART et al. 1987 and NAGEL et al. 2002). Significant differences appear in the way that authors define the modifier and then reduce potential tree growth to the certain tree status. ARNEY (1972) employs live crown length and total height ratio as modifiers. KRUMLAND (1982), WENSEL et al. (1987) and BURKHART et al. (1987) define the modifier by estimating canopy closure at 66% (CC66) of total tree height. RITCHIE & HANN (1986) define their modifier as a function of tree height, dominant stand height ratio and crown ratio.

PRETZSCH et al. (2002) employs crown surface area, the CI provided by PRETZSCH (1995) and tree type specific values. NAGEL et al. (2002) employs the ratio between stand top height and tree height. The model developed by BURKHART et al. (1987) managed to explain 46% of height increment variation, whereas those developed by PRETZSCH et al. (2002) and RITCHIE & HANN (1986) were able to explain 52% and 70.8% of height increment variation respectively.

To conclude, modelling approaches based on the potential modifier method is more common in the literature. Potential growth is estimated by applying mean stand height or stand top height relations with MSA. Modifier simply expresses tree vigour. For this purpose live crown ratio, ratio of actual volume of foliage to maximum volume of foliage, CIs or stand top height and tree height ratio could be used depending on the data available.

2.4.6 Methods to model natural tree mortality

VANCLAY (1994) classifies tree mortality that influences forest growth into two groups: natural mortality and anthropogenic mortality. Further, natural mortality is split into regular mortality that refers to ageing, suppression and competition as well as normal incidence of pests, diseases, and weather conditions. Catastrophic mortality includes wildfire, occasional but severe losses from "abnormal" weather conditions, and major pest and disease outbreaks. Anthropogenic mortality refers to planned harvesting, silvicultural treatment and damage from silvicultural activities. BIGLER & BUGMANN (2003) and OZOLINČIUS et al. (2005) separate growth dependent mortality (related to competition for growing space between trees) and growth independent mortality (related to ageing of trees, diseases, pest outbreaks, wildfire and weather conditions). This study focuses only on growth dependent mortality.

Modelling of growth dependent mortality is implemented by applying deterministic or stochastic models (HAWKES 2000). EK (1980) and WEBER et al. (1986) found no difference between the results of deterministic and averaged stochastic projections. Yet, deterministic models are applied to model mortality in stand level and stochastic models are very useful to model the probability of natural mortality of each tree in the stand. Some authors as WOOLLONS (1998), EID & ØYEN (2003) and ZHAO et al. (2007) combine these two methods.

Deterministic models. Cumulative probability distributions are appropriate models for mortality in even-aged stands due to their ability to describe the development of stem numbers over time. The Weibull distribution, gamma distribution, negative binomial distribution, and a distribution derived from the Richards function showed comparably good fits to cumulative mortality data (BUFORD & HAFLEY 1985). GLOVER & HOOL (1979), SOMERS et al. (1980) and WOOLLONS & HAYWARD (1985) also reported Weibull distribution models to be compatible with analysed data.

Other modelling approaches are based on stand density rule proposed by REINEKE (1933) (for description see subsection 3.7.3) or the -3/2 power rule developed by YODA et al. (1963). The stand density rule describes the relationship between quadratic mean diameter and stem number per hectare in a fully stocked, unmanaged, pure even aged stand. With slope coefficient b=-1.605, an increase in quadratic mean diameter by 1% results in a decrease of tree numbers by 1.605% (PRETZSCH 2009). Stand density rule in modelling natural mortality was applied by CLUTTER et al. (1992), HYNYNEN (1993), TANG et al. (1994), AMATEIS et al. (1997), VANCLAY & SANDS (2009) and others. The power rule developed by Yoda et al. 1963 describes the relationship between the mean shoot weight and plant number per hectare. This rule could be simply reformulated in the form where number of growing trees per hectare equals to quadratic mean diameter raised to the power by minus 2 (PRETZSCH 2009). This concept in modelling natural mortality was applied by DREW & FLEWELLING (1977), DREW & FLEWELLING (1979), VANCLAY & SANDS (2009) and others.

Stochastic models predict the probability of natural mortality of each tree in the stand. For this purpose MONSERUD (1976) tested discriminant, probit and logit functions and concludes that the logistic equation provides the greatest discriminating power for predicting live and dead trees. During recent decades many logistic models to predict natural mortality have been developed. AVILA & BURKHART (1992), DURSKY (1997) and DOBBERTIN & BRANG (2001) argue that prediction accuracy is a valuable criterion for comparing logistic models of tree mortality. CROW & HICKS' model (1990) correctly classified 78% dead and 64% of live trees; EID & TUHUS' model (2001) correctly classified 75.9% of dead trees and BIGLER & BUGMANN'S model (2003) correctly classified 79.6% of dead and alive trees.

MONSERUD (1976) contends the probability of survival is exceedingly well defined by function of tree size and CI. HAMILTON (1986) complements these findings by stating that variation in mortality could be explained by a measure of tree size, stand density, individual tree competition and growth rate. Most of the authors that have investigated the probability of natural tree mortality expressed tree size by tree diameter at breast height (MONSERUD 1976, HAMILTON & EDWARDS 1976, WYKOFF et al. 1982, BUCHMAN 1983, HAMILTON 1986, WYKOFF 1986, HANN & WANG 1990, CROW & HICKS 1990, VANCLAY 1991b, DURSKY 1997, MURPHY & GRANEY 1998, MONSERUD & STERBA 1999, JURKONIS 2004, YANG et al. 2003, ZHAO et al. 2004, TEMESGEN & MITCHELL 2005, JUKNYS et al. 2006, BRAVO-OVIEDO et al.

2006, SCHRÖDER et al. 2007, SIMS et al. 2009 and ADAME et al. 2010) or by tree height (HAMILTON & EDWARDS 1976, DURSKY 1997, SCHRÖDER et al. 2007, SIMS et al. 2009).

Individual tree competition is mainly expressed by distance independent CI basal area of larger trees (BAL) (see HANN & WANG 1990, MURPHY & GRANEY 1998, MONSERUD & STERBA 1999, YANG et al. 2003, TEMESGEN & MITCHELL 2005, BRAVO-OVIEDO et al. 2006, and SIMS et al. 2009). Also individual tree competition is estimated by tree diameter and quadratic mean diameter ratio (see HAMILTON 1986, WYKOFF 1986, BURGMAN et al. 1994, SIMS et al. 2009) or vice versa quadratic mean diameter and tree diameter ratio (see AVILA & BURKHART 1992, LYNCH et al. 1998). In the same manner the competitive situation of trees could be expressed by tree height and mean stand height ratio (see AVILA & BURKHART 1992, SIMS et al. 2009, ADAME et al. 2010). The other expressions of tree competitive situation are area overlap index (MONSERUD 1976), relative size (SIMS et al. 2009), and relative basal area CIs (ZHAO et al. 2004, SIMS et al. 2009).

Various researchers express tree vigour by predicted diameter growth (MONSERUD 1976) or by diameter increment in a previous period (BUCHMAN 1983, HAMILTON 1986, WYKOFF 1986). Additionally, basal area increment in the last period is used to express tree vigour (see DURSKY 1997, and SCHRÖDER et al. (2007). Independent variables like crown ratio (HANN & WANG 1990, AVILA & BURKHART 1992, MONSERUD & STERBA 1999), tree diameter at breast height and tree height ratio (SCHRÖDER et al. 2007), tree defoliation (DOBBERTIN & BRANG 2001, JURKONIS 2004 and JUKNYS et al. 2006) or crown class (ZHAO et al. 2004) are also used to define tree vigour status.

The most widely used stand level independent variable is stand basal area (HAMILTON 1986, LYNCH et al. 1998, MURPHY & GRANEY 1998, YANG et al. 2003, ZHAO et al. 2004, TEMESGEN & MITCHELL 2005, BRAVO-OVIEDO et al. 2006). Stand site quality or site index is the second most important stand level independent variable (HANN & WANG 1990, BURGMAN et al. 1994, DURSKY 1997, MURPHY & GRANEY 1998, BRAVO-OVIEDO et al. 2006) and MSA was the third most important stand level independent variable (BURGMAN et al. 1994, MURPHY & GRANEY 1998, JURKONIS 2004, JUKNYS et al. 2006). The other stand level independent variables like quadratic mean diameter (BURGMAN et al. 1994, MURPHY & GRANEY 1998 ZHAO et al. 2004), mean stand height (LYNCH et al. 1998) or stocking (BURGMAN et al. 1994) are also used to model the probability of natural tree mortality.

Mortality likelihood (ML) functions modify the values of probability of natural tree mortality ranging from 0 to 1 into likelihood values generating mortality as observed in the field for given intervals of probability of natural tree mortality (SCHRÖDER et al. 2007). Some authors check the third step by comparing ML values with the equally distributed random values (MR). If the value of ML is greater than MR, the tree is classified as dead (DURSKY 1997).

To conclude, deterministic models are applied to model mortality at stand level and stochastic models are very useful to model the probability of the natural mortality of each tree. Thus, stochastic models are recommended. Due to possessing the greatest discriminating power, stochastic logit functions should be used. The most appropriate independent variables used to model natural tree mortality are tree diameter at breast height, tree height, distance independent CIs, tree diameter and quadratic mean diameter ratio, diameter or basal area increment in previous period, MSA, site index and stand basal area.

2.5 Evaluation of forest growth models

The meaning of evaluation in Merriam-Webster's collegiate dictionary is defined as determination of the significance, worth, or condition by careful appraisal and studies (MISH 2005). Effective model evaluation includes qualitative as well as quantitative examinations of the model (SOARES et al. 1995). By contrast, the validation of growth models is defined only by quantitative comparisons of model simulations to actual growth behaviour (PRETZSCH 2009).

According to VANCLAY (1994), SOARES et al. (1995), VANCLAY & SKOVSGAARD (1997), BURKHART & TOME (2012) model evaluation is implemented in five steps. The first deals with the model's logic, theoretical and biological behaviour. The second requires estimating the statistical properties of the model, such as the parameters in model functions. The third concerns checking that all the regression assumptions of the model are satisfied. The fourth tests the model by applying independent data, and the fifth focuses on sensitivity analysis.

PRETZSCH (2009) provides a slightly different structure for model evaluation, reducing the process to three steps. The first checks the suitability of the model selected. The second checks the validity of the biometric model developed, and the third checks the suitability of the software used to translate the biometric model.

The presented principles of a model's evaluation sets the framework for the assessment of the selected STLS for Lithuania. The model's logic behaviour, statistical properties, regression assumptions, validation procedures and suitability of the software used have to be precisely checked.

2.6 Concluding remarks

Forest management history in Europe passed through three important periods: pre-industrial, industrial and post-industrial period. Historical events shaped the traditions of Lithuanian forestry management. The leading forest management theory in Lithuania till the end of 20th century was 'normal forests' theory enlarged by principles of multipurpose and continuous forest usage. Ratification of the Rio de Janeiro convention on biological diversity in 1995, and adoption of principles of sustainable forest management introduced some research changes in forest growth and yield. New breakthroughs could be based on growth and yield studies of more structured mixed uneven aged forests and forest growth models for ecosystem management.

Forest productivity is a complex issue, influenced by numerous various factors like climatic conditions, genetic material, site productivity, tree age, stand structure and silvicultural treatments. Thus, appropriate forest management tools are required. The present status of research in Lithuania requires development of a STLS.

Distance independent CIs developed by HEGYI (1974) and WYKOFF et al. (1982) still have high capacities to describe tree growth. However, distance dependent selection methods, based on inverse angle gauge approach are the most appropriate. For estimating the strength of competition, the equations developed by HEGYI (1974), BIGING & DOBBERTIN (1992), PRETZSCH (1995) and SCHRÖDER (2004) have the highest influence on tree growth.

The basal area increment model developed by SCHRÖDER et al. (2007) manages to explain a reasonable proportion of basal area increment variation, and is therefore appropriate for further analysis. Yet, to avoid pseudo linearity, development of original nonlinear diameter increment models is also recommended.

The approach of tree height increment modelling, based on the potential modifier method, is the more common approach in the literature. Potential growth is estimated by applying mean stand height or stand top height relations with MSA.

In order to model natural tree mortality stochastic logit functions, due to possessing the greatest discriminating power, should be used.

To summarise the presented results, the selected STLS for Lithuania, has to be evaluated according to clarified evaluation procedures. The model's logic behaviour, statistical properties, regression assumptions, validation procedures and suitability of the software used have to be precisely evaluated.

3 MATERIALS AND METHODS

3.1 Growth and climatic conditions in Lithuania

Distribution of soil types in Lithuania. The FAO World Reference Base for Soil Resources distinguishes 12 main soil types: regosols, leptosols, cambisols, luvisols, planosols, albeluvisols, arenosols, podzols, gleysols, histosols, fluvisols and anthrosols (FOOD AND AGRICULTURE ORGANISATION OF UNITED NATIONS 2013). In the context of this study the distribution of soil types will be divided into Regions 1-4 and compass directions within a particular region (N-north, E-east, S-South and W-west) in Figure 3-6, for example henceforth R3W – Region 3 west.

Regosols or weakly developed mineral soils are mainly located in the Aukštaičių (R2W), Žemaičių (R2S) and South Lithuanian highlands (R4). Cambisols, the most productive soils are located in the central lowland plains of Lithuania (R2). Luvisols are characterised by high nutrient content, and good drainage and are distributed in western coastal regions of Lithuania and in the eastern parts of the Aukštaičių highlands (R2W). Planosols, with a surface horizon that shows signs of periodic water stagnation and subsoil with significantly more clay than the surface horizon, are located around Kaunas (R3NW) and Šalčininkai (R4E). Albeluvisols, characterised by bleached subsurface horizon, are distributed in the west (R1) and east (R3). Arenosols, consisting of unconsolidated sand deposits, are mainly located in the eastern (R3) and far south sandy regions (R4). Podzols, sandy soils under layer of ash, are distributed in Vilnius (R3E), Kaunas (R3NW), Panevėžys (R2central) and Šilutė (R1SW) regions. Gleysols, a wetland soil that is saturated with groundwater for sufficiently long periods to develop a characteristic gleyic colour pattern, are equally distributed around the country. Histosols, consisting of primary organic materials, are distributed in Žemaitija (R1SE) and the south-east of Lithuania (R4E). Finally, Fluvisols, that are mainly formed in alluvial deposits, are located in the floodplains of the biggest rivers e.g. the Nemunas (flowing from R4S to R3N to R1W), Neris (flowing from R3E to join Nemunas R3N) Venta (flowing from R2 centre northwest to Latvia) etc. The proportions of analysed soils by area are: luvisols 21%, albeluvisols 20.38%, cambisols, 16.8%, arenosols 11.93%, histosols 9.54%, gleysols 8.58%, podzols 6.74%, fluvisols 3%, planosols 1.6% and regosols 0.36% (MOTUZAS et al. 2009). Productive or very productive soils (luvisols, albeluvisols and cambisols) equate to around 58%, sandy soils (arenosols, podzols, and regosols) form 19% and wet soils (histosols, gleysols and planosols) make 20% of total soil area. The most productive soils are mainly distributed in central Lithuania (R2S) and the poorest soils are located in the east (R3E) and far south (R4S).

Climatic conditions. A maritime climate is only found in the western coastal area of Lithuania (R1W), because continentallity increases from the western coastal areas towards the eastern borders (BUKANTIS 1994). To define climatic conditions in year of 2009, the study chose four climatic variables: mean annual, maximum and minimum temperatures (Figure 3-1) and mean annual precipitation (Figure 3-2), all of which ŽVILIUS (2010) presented. Mean annual temperature decreases from 8 to 5.5^{0}C from west (R1W) to east (R3E). The lowest of the absolute maximum and minimum temperatures occur in the west (32.8 and minus 27.8^{0}C) (R1W) and the highest in the south-east (35.6 and minus 35.9) (R4E) see Figure 3-1.

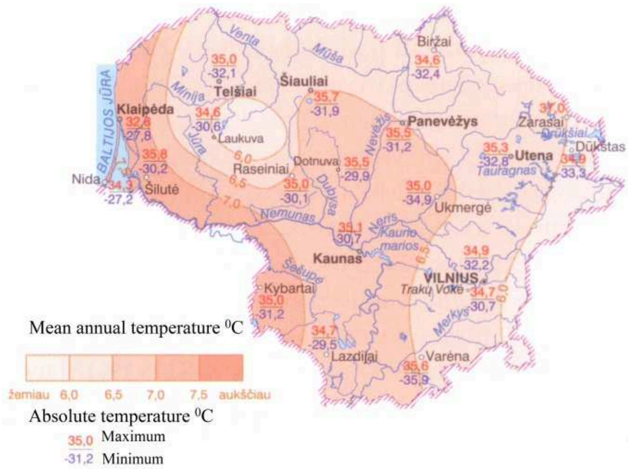


Figure 3-1: Mean annual temperature in Lithuania. Source: (ŽVILIUS 2010).

Mean annual precipitation is, at 850 mm year^{-1}, highest in the west and the lowest, at 600 mm year^{-1}, in the central-north and south-west (ŽVILIUS 2010).

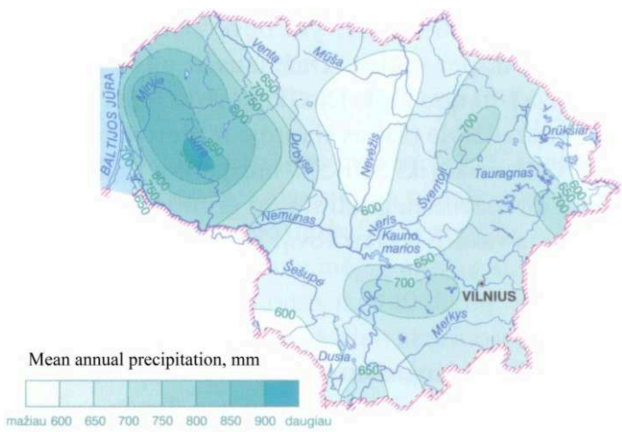


Figure 3-2: Mean annual precipitation in Lithuania. Source: (ŽVILIUS 2010).

In summary, Lithuania has high proportion of productive soils and climatic conditions suitable for growing most of the tree species in Europe.

3.2 Forest resources in Lithuania

In the 16th century forestry covered an estimated 60% of Lithuania. Severe overexploitation during the 1940s reduced coverage to less than 20% in 1948 (Figure 3-3, KULIEŠIS et al. 2011). Forestry recovered during the second half of the 20th century, attaining in 2011 coverage of 33.2% of land area, equating to 2.06 million hectares of forest stands.

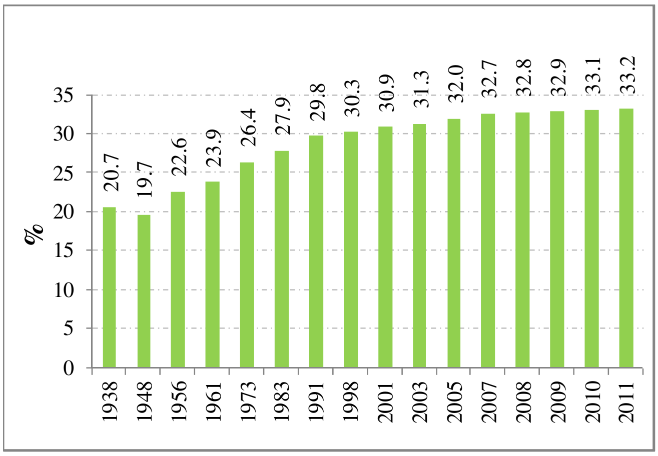


Figure 3-3:Forest coverage in Lithuania 1938-2011. Source: (KULIEŠIS et al. 2011).

During the same period, 1948-2011, the growing stock volume in Lithuanian forests followed the same trend increasing from 125 to 490 million m^3 (Figure 3-4, KULIEŠIS et al. 2011).

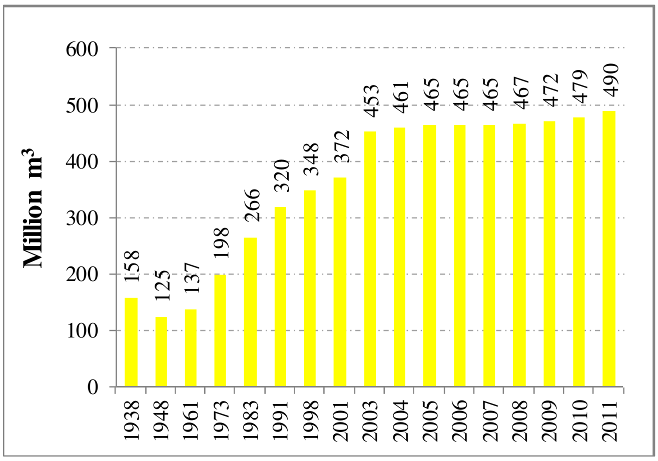


Figure 3-4: Growing stock volume million [m^3], 1938-2011. Source: (KULIEŠIS et al. 2011).

Lithuanian forest land area is allocated to four forest management groups: (i) forest reserves 1.2%, (ii) ecosystem protection and recreational 12.2%, (iii) protective forests 15.2%, and (iv) exploitable forests 71.4%, (KULIEŠIS et al. 2011). Forestry ownership categories, up to the 01.01. 2011, consists of: land of State importance 49.6%, private forests 38.6% and forests reserved for restitution and property rights 11.8% (KULIEŠIS et al. 2011).

For the main characteristics of forest stands, by species, in Lithuania see Table 3-1. The total forest stand area, in 2011, is 2,057,500 hectares. The dominant three species, by proportion of total forest stand area are pine (35.3%), birch (22.2%), and spruce (20.8%). Other broadleaved species like aspen, black and grey alders, oak and ash cover, between them, no more than 21.6% (KULIEŠIS et al. 2011).

While the mean age of forest stands in Lithuania is 53 years, the mean age of pine stands is 66 years. The site index for Lithuanian forest stands is 26.3 metres at the base age and for pine stands is 27.6 metres at the base age. The stocking level (SL) for all Lithuanian forest stands is 0.76, but comparably high for pine stands at 0.8. Growing stock volume by species is greatest for pine both for all stands (297 m^3 ha^{-1}) and $Mat^{101\text{-}140}age$ stands (375 m^3 ha^{-1}). Gross annual volume increment for all stands is 8 m^3 ha^{-1} and for pine stands 8.6 m^3 ha^{-1}.

Table 3-1: Characteristics of forest stands in Lithuania 2011.

Dominant tree species	**Area**		**Characteristics of forest stands**					
			Age, years	**Site index H_{AB}**	**Stocking level**	**Growing volume m^3 ha^{-1}**		**Gross annual increment m^3 ha^{-1}**
	1000 ha	**%**				**All stands**	**Mature***	
Pine	727.1	35.3	66	27.6	0.8	297	375	8.6
Spruce	427.8	20.8	47	28.7	0.68	212	354	7.9
Birch	456.5	22.2	46	25.7	0.77	196	287	7
Aspen	79.1	3.8	42	28.8	0.71	251	347	9.3
Black alder	140.6	6.8	43	23.3	0.84	223	335	8.7
Grey alder	129.1	6.3	33	16.7	0.74	156	191	7.6
Oak	41.4	2.0	77	26.7	0.69	229	317	6.6
Ash	36.3	1.8	65	28.4	0.5	208	255	5.7
Other	19.5	0.9	43	21.1	0.6	165	218	6.7
Total	2057.5	100	53	26.3	0.76	237	307	8

* Mature – 101-140 years old.
Source: for characteristics of forest stands part (KULIEŠIS et al. 2011).

Pine is one of the most important tree species in Lithuania that grows on poor soil sites, but still generates comparably high amounts of volume increments. Due to forest management traditions, pine is grown mainly in pure stands.

3.3 General research structure

The objective and tasks of this dissertation's research were formulated earlier (see subsection 1.2). In order to promote readers understanding, the overall research structure is presented in Figure 3-5. The overarching objective for the study was to adapt an STLS for Lithuanian pine forests, growing on mineral sites.

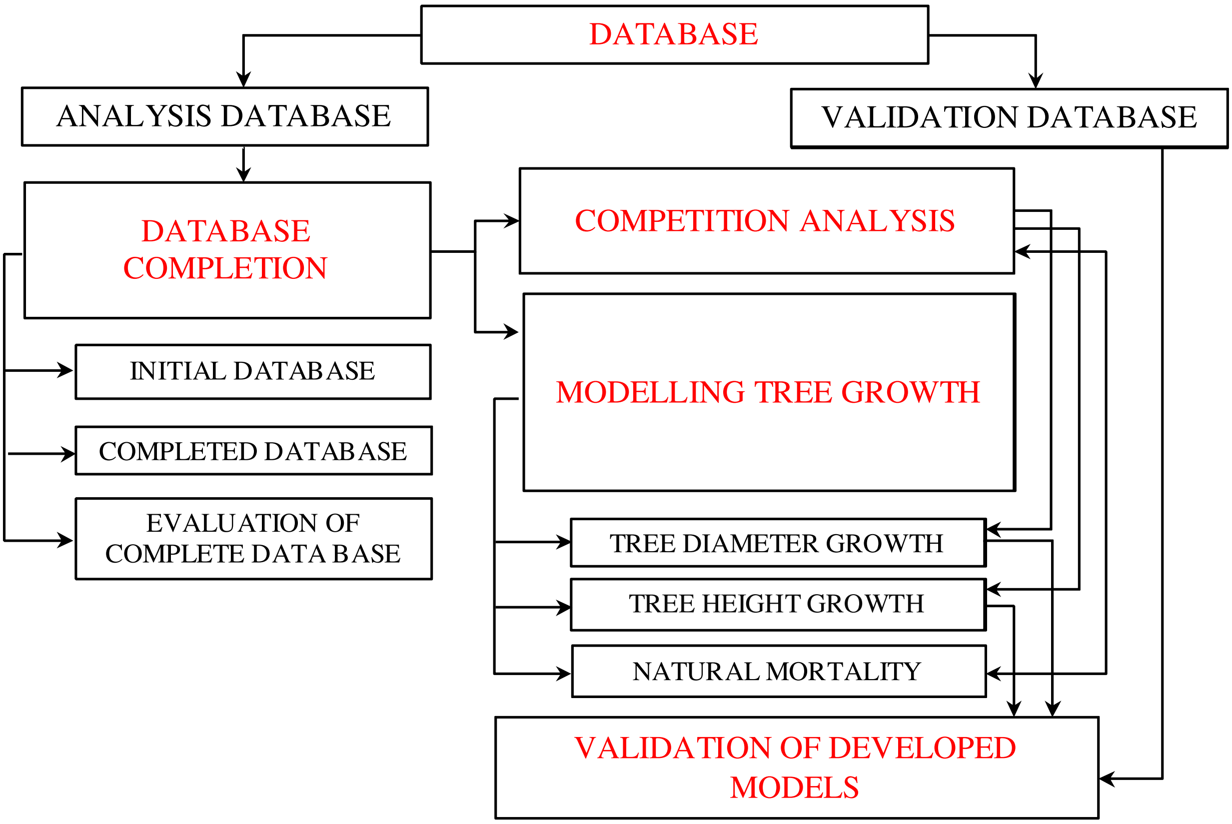


Figure 3-5: Overall research structure.

The first research task requires the creation and subsequent evaluation of a database to be used for modelling. For this purpose, the database consists of two parts: an analysis database (to develop the models) and a validation database. The analysis database focuses on the modelling of missing data values and the validation database on evaluating the compatibility of data that come from six sequential inventories.

The second research task focuses on competition for growing space to diameter, basal are and height growth of trees. The CIs will be evaluated and the best one selected for further modelling.

The third research task concerns the modelling of tree growth, which comprises of three parts: 1) tree diameter increment, 2) tree height increment and 3) assessing natural tree mortality. The fourth research task is to evaluate the models by applying the validation database. This final task will indicate whether or not the models provide plausible results.

3.4 Experimental data applied in the research

3.4.1 Distribution of permanent experimental plots

KULIEŠIS (1997a) divides Lithuania into four main forest productivity regions (see Figure 3-6) that are based on the dominant tree species: 1) Mixed spruce forests of Samogitia, 2) Mixed productive forests of central Lithuania, 3) Mixed pine-spruce forests of south-eastern Lithuania, 4) Pure pine forests of southern Lithuania. The variations in the mean gross annual increment by region are: Region 1 - 6.1 to 6.7 m^3 ha^{-1}; Region 2 - 6.5 m^3 ha^{-1}; Region 3 - 6.0 to 7.2 m^3 ha^{-1} and Region 4 - 5.3 to 6.8 7 m^3 ha^{-1} (KULIEŠIS 1997a).

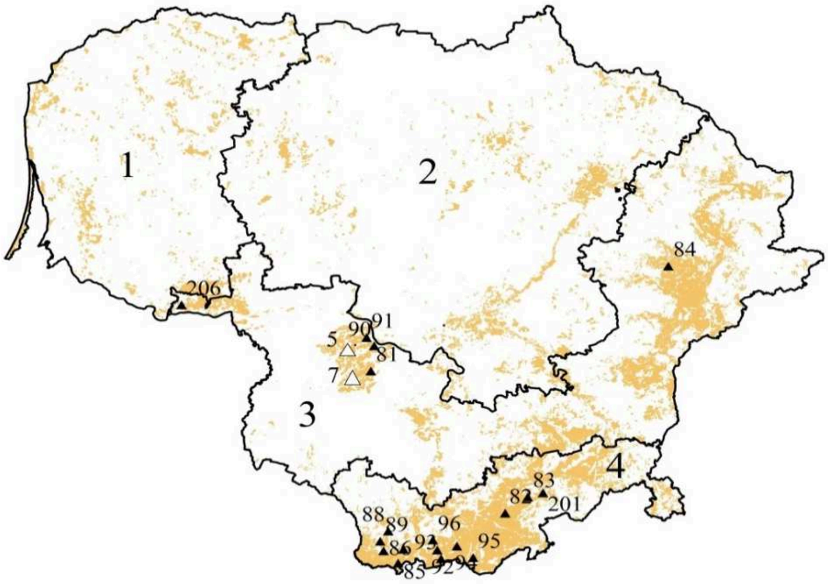


Figure 3-6: Lithuania's pine productivity by regions, permanent experimental and validation plots. Source: author's own work set in regions defined by Kuliešis (1997a).

Key: Regions: 1-4, ▲ Permanent experimental plots: 81-206, △validation plots 5-7, Pine forests.

The study involved 18 permanent experimental plots (PEPs), numbers 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 201 and 206 represent the analysis data (black triangles) and two validation plots (VPs), 5 and 7, represent the validation data (white triangles). The PEPs were established in the areas of Lithuania where pine forms the highest ratio in species composition. Thus in Regions 1 and 2, there are not any PEPs. In Region 3 there are seven PEPs: numbers 81, 84, 90, 91 and 206 and the two VPs numbers 5 and 7. A further 13 PEPs: 82, 83, 85, 86, 87, 88, 89, 92, 93, 94, 95, 96 and 201 are sited in Region 4.

3.4.2 Standard description of permanent experimental plots

During the 1983-1985 period, 16 PEPs were established in older, naturally regenerated, single-layered stands that grow on very typical pine sites (KULIEŠIS 1989b). The other 2 PEPs (201 and 206) were established in 1990 and 1992 on artificially regenerated young pine stands (KULIEŠIS & SALADIS 1998). The process of establishment was conducted by LAMMC Forest Institute scientists. The validation plots (VP) were established in 1983 in Region 3 (PETRAUSKAS 1990, Table 3-2, Appendix 2).

The area of the PEPs varied from 0.1 to 0.6 ha due to the various densities of naturally regenerated stands. In order to have a 5% sample of a particular species, the last measurement requires to have at least 200 representatives of that species (ANTANAITIS et al. 1975). The highest initial densities occurred in the youngest plots - PEP 201 (5403 trees ha^{-1}) and PEP 206 (4906 trees ha^{-1}). By contrast, the lowest density occurred in the oldest stands PEP 81 (474 trees ha^{-1}) and PEP 91 (431 trees ha^{-1}) (see Table 3-2).

Table 3-2: Characteristics of permanent experimental plots.

Plot	Size ha	Vegetation types	Year of establishment	Age	Storey	Species	N ha^{-1}	Regeneration
			Experimental data					
81	0.54	*Myrtillosa*	1983	75	I	10P	474	Spruce, Oak
82	0.25	*Myrtillosa*	1983	31	I	10P	1000	Spruce, Birch, Aspen
83	0.64	*Vaccinio-myrtillosa*	1983	61	I	10P	592	Spruce, Birch, Oak, Maple
84	0.42	*Vaccinio-myrtillosa*	1983	40	I	10P	995	Spruce
85	0.42	*Vaccinio-myrtillosa*	1984	50	I	10P	964	
86	0.25	*Vacciniosa*	1984	48	I	10P	2328	
87	0.25	*Vaccinio-myrtillosa*	1984	50	I	10P	1560	Spruce
88	0.17	*Vaccinio-myrtillosa*	1984	29	I	10P	3041	
89	0.25	*Vaccinio-myrtillosa*	1984	39	I	10P	1644	
90	0.42	*Vaccinio-myrtillosa*	1984	66	I	10P	814	
91	0.51	*Vaccinio-myrtillosa*	1984	72	I	10P	431	Spruce, Oak
92	0.42	*Vacciniosa*	1984	60	I	10P	1017	
93	0.16	*Vacciniosa*	1984	38	I	10P	1850	
94	0.49	*Vacciniosa*	1984	67	I	10P	716	
95	0.36	*Cladoniosa*	1984	68	I	10P	925	Birch
96	0.1	*Vacciniosa*	1984	44	I	10P	2865	
201	0.36	*Vaccinio-myrtillosa*	1990	8	I	10P	5403	
206	0.22	*Vaccinio-myrtillosa*	1992	7	I	10P	4906	
			Validation data					
5	0.25	*Vaccinio-myrtillosa*	1983	34	I	10P	2096	
7	0.4	*Vaccinio-myrtillosa*	1983	60	I	7P2S1B	583	Spruce

Where: P=Scots pine; S=Norway spruce; B=Silver birch.

The selected vegetation types of PEPs cover a wide range of the site conditions and include *Cladoniosa, Vacciniosa, Vaccinio-myrtillosa, Myrtillosa.* These are the main vegetation types for growing pine stands in Lithuania. The age of the stands in the PEPs at the beginning of research programme ranged from 7 to 75 years, and since experiment lasted for 30 years, the age coverage interval increased up to over 100 years. All PEPs stands are single-layered monocultures of pine, with a pine proportion close to 100% (10P). Yet, regeneration of spruce, birch, aspen, oak and maple was also recorded.

The VPs were established on *Vaccinio-myrtillosa* site types. The initial ages of the stands ranged from 34 to 60 years, and by the end of experiment had reached 90 years. The stand in VP 5 is a single-layered monoculture of pine, with a pine proportion close to 100% (10P). The stand in VP 7 is pine, spruce, birch mix dominated by pine (70%), spruce (20%) and birch (10%) (see Table 3-2, 7P2S1B).

3.5 Features of data collection and field measurements

3.5.1 Establishment of permanent experimental plots

The experimental design of the older PEPs 81-96 was different to that of the younger PEPs 201and 206. To visualise the structure of PEPs in older stands, PEP 89 was selected as an example (Figure 3-7). In this case the length and the width of the permanent experimental plot were each equal to 50 metres. In other PEPs the measurements varied from 31 to 80 metres. Next, PEP 89 was divided into 9 subplots, with exactly measured centres (red dots) and coordinates. Each subplot had its own tree left-right numbering system that started from the top left corner. The distance and the azimuth from the centre of the subplot to the subject tree were recorded (KULIEŠIS 1989b).

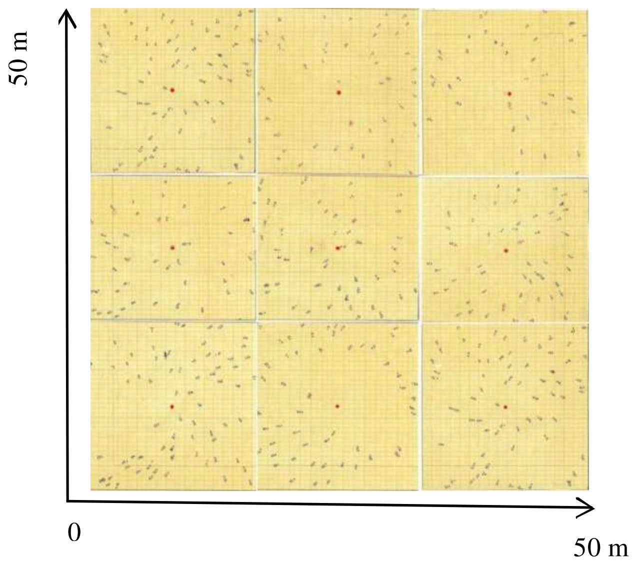


Figure 3-7: The structure of permanent experimental plot number 89.

The experimental design of PEPs 201 and 206 is remarkably different. A detailed description of the experimental design can be found in KULIEŠIS & SALADIS (1998). These plots were established to investigate the impact of thinning on the growth of pine stands. Thus, the PEPs were divided into 10 subplots, each of which was grown with various densities of trees. For this study, only 2 subplots in each of PEP 201 and 206 with no thinning intervention or control subplots were taken into account. The trees in the subplots of PEPs 201 and 206 were counted in a continuous 'snaking' line moving from the bottom right corner to the top left corner. Coordinates of trees were defined by measuring the distances between and inside the rows (KULIEŠIS & SALADIS 1998).

3.5.2 Measurements of trees in permanent experimental plots

Measurements of trees in PEPs were done by applying unified forest measurement methodology in Lithuania, defined by KULIEŠIS & SALADIS (1998). In each PEP, were recorded the following data for every tree: tree species, status of tree (growing, damaged or dead), diameter at breast height (d_{bh}), and horizontal position. Tree height (h), tree height to crown base (h_{cb}), crown width (cw) and age were measured only for sample trees. Later, from periodic measurements, tree diameter and height increments have been calculated.

The d_{bh} (1.3 metre from the root collar) measurements were done by using tree calliper. To assure that measurements were done always in the same direction, perpendicular arms of tree calliper had to be directed to the centre of subplots. The smallest grade of tree calliper was millimetre therefore that was accepted as a possible error.

The h, h_{cb} and cw were measured only for sample trees. Each 5th tree in the plot was selected as a sample tree. So each plot had from 40 to 60 (depending on the tree density of the plot) sample trees. During the measuring period some sample trees had died. In this case, the next tree on the list was selected as the sample tree.

The h and h_{cb} were measured by using clinometer. The precision of clinometer was ±0.5 metre. To define h_{cb} position, the method proposed by BIGING & WENSEL (1990) was applied. The bottom of the crown in this method was visually averaged to the point that shows the mean height of crown base (see Figure 3-8).

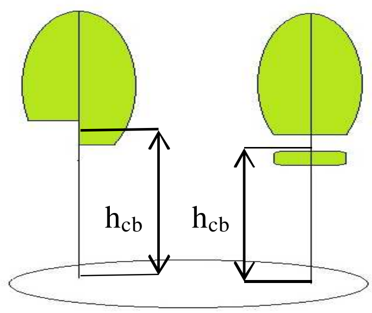


Figure 3-8: Determination of tree height to crown base (h_{cb}) by averaging. Source: BIGING & WENSEL (1990).

The cw measurements were done according to RÖHLE (1986) methodology. Firstly, four measurements of cr_{rad} according to the main compass directions: north, east, south and west were done by using tape measure. The cw measurements with the tape were precise as ± 0.1 metre (RÖHLE 1986). The final cw value is obtained by employing Equation 3-1. The cr_{rad} for the sample trees were measured only in the last inventory, thus for previous inventories, cw values had to be modelled.

$$cw = \frac{cr_{rad_{north}} + cr_{rad_{south}} + cr_{rad_{east}} + cr_{rad_{west}}}{20} \tag{3-1}$$

Where: cw=crown width in m; $cr_{rad_{north}}$=crown radius to north direction in decimetres (dm); $cr_{rad_{south}}$=crown radius to south direction in dm; $cr_{rad_{east}}$=crown radius to east direction in dm; $cr_{rad_{west}}$=crown radius to west direction in dm.

Position of each tree was defined while establishing the PEPs. For this purpose, the distance and the azimuth for each tree from the centre of the subplot was measured. The distance was measured with tape and azimuth with compass called bussola. Normally, the declination of compass is 15 minutes. While estimating exact tree positions, the source of errors had been the estimation of centre coordinates for each subplot, the angle and the distance errors from the centre of subplot. Having this data it is easy to find tree coordinates x_{coord} and y_{coord} regarding to lower left corner of the permanent experimental plot, by employing Equations 3-2 and 3-3 (VARIAKOJIS 1984).

$$y_{coord} = Y_{coord} + dist \cdot \cos\theta \quad (3\text{-}2) \qquad x_{coord} = X_{coord} + dist \cdot \sin\theta \quad (3\text{-}3)$$

Where: x_{coord} and y_{coord}=target tree coordinates; X_{coord} and Y_{coord}=coordinates of the centre of subplot; dist=distance from the centre of subplot to target tree in m; θ=azimuth of the tree.

During the first inventory the ages of trees were measured in the following way. Firstly, for some trees, increment cores at the breast height were taken with an increment borer. Then, annual rings for each core were counted and the number of years (5 years in Lithuania) required for reaching the height of 1.3 metre was added (HUSCH et al. 2003).

3.5.3 Estimation of stand level parameters

Usually, to describe the growth process and dynamics of forest stands, a standard analysis of the PEPs was performed, in which the initial stand is split into three categories: remaining, removal and total (KULIEŠIS 1993).

The mean stand age (MSA) was calculated as the mean age of the measured trees in each PEP in the first inventory. The MSA for subsequent inventories was calculated by adding the accumulated number of intervening years between the first and subsequent inventories.

The remaining stand was described using the following parameters: the number of growing trees per hectare (N), mean stand height (H_q), quadratic mean diameter (D_q), stand top height (H_{100}), stand top diameter (D_{100}), basal area (BA), standing volume (V). The removed stand was described using the following parameters: the number of self-thinned trees per hectare ($N_{removed}$), mean height ($H_{q\ removed}$), quadratic mean diameter ($D_{q\ removed}$), basal area ($BA_{removed}$) and volume ($V_{removed}$) of removed stand. In order to characterise the total stand, estimates of gross volume yield (GY), periodic annual volume increment (PAI_V) and the percentage of self-thinned trees from the periodic annual volume increment during the analysed period $PAI_{removed}$ were used.

The number of growing (N) or self-thinned trees per hectare ($N_{removed}$) is calculated by dividing the number of growing or self-thinned trees per plot by plot size, measured in hectares. The D_q for remaining and removed stand is calculated by using Equation 3-4. It is then possible to estimate H_q for the remaining and the removed stands by entering the value of the D_q of the remaining or removed stand into Equation 3-5, with the same regression coefficients a_0 and a_1 estimated by using Equation 3-18.

$$D_q = \sqrt{\frac{\sum_{i=1}^{K} d_{bh_i}^{\ 2}}{K}} \qquad (3\text{-}4) \qquad\qquad H_q = 1.3 + e^{\left(\frac{a_0}{D_q} + a_1\right)} \qquad (3\text{-}5)$$

Where: D_q=quadratic mean diameter in cm; H_q=mean stand height in m; d_{bh}=tree diameter at the breast height in cm; K=number of trees per plot; a_0 and a_1=regression coefficients taken from Equation 3-18.

In order to calculate the top diameter of the remaining stand (D_{100}), instead of all trees, the diameters of the 100 largest growing trees per hectare are taken and calculated using Equation 3-6 (KRAMER & AKÇA 2002). The top height of the remaining stand is calculated by using Equation 3-7 with the same regression coefficients a_0 and a_1 as in Equation 3-5.

$$D_{100} = \sqrt{\frac{\sum_{i=1}^{100} d_{bh_i}^{\ 2}}{100}} \qquad (3\text{-}6) \qquad\qquad H_{100} = 1.3 + e^{\left(\frac{a_0}{D_{100}} + a_1\right)} \qquad (3\text{-}7)$$

Where: D_{100}=stand top diameter in cm; H_{100}=stand top height in m; d_{bh}=tree diameter at the breast height in cm; a_0 and a_1=regression coefficients taken from Equation 3-18 (MICHAILOFF 1943).

Basal area of remaining (BA) or removal ($BA_{removed}$) stand is calculated using Equation 3-8, by taking into account the diameter of trees that survived (remaining stand) or were self-thinned (removed stand) during the interval between inventories. Volume (V) is calculated in the same way using Equation 3-9 taking into account volumes of trees that survived (remaining stand) or were self-thinned (removed stand) during the interval between inventory.

$$BA = \frac{\pi \cdot \sum_{i=1}^{K} d_{bh_i}^{\ 2}}{40000 \cdot S_{plot}} \quad (3\text{-}8) \qquad V = \frac{\sum_{i=1}^{K} v_i}{S_{plot}} \quad (3\text{-}9)$$

Where: BA=basal area of remaining or removed stand [m^2 ha^{-1}]; V=standing or removal volume [m^3 ha^{-1}]; d_{bh}=tree diameter at the breast height in cm; v=tree stem volume [m^3]; K=number of trees per plot; S_{plot}=the size of the plot ha.

The methods to calculate parameters that describe total stand are: (i) gross volume yield (GY) calculated as a sum of the volume of remaining stand in current inventory ($V_{(t)}$) and removed stand ($V_{removed}$) in the last and previous inventory periods (Equation 3-10). The volume of the removed stand calculated in the first inventory was not included, because the dates of tree exclusions were not known.

$$GY = V_{(t)} + \sum_{inv=2}^{6} V_{removed_{inv}} \quad (3\text{-}10)$$

Where: GY=gross volume yield in the current inventory [m^3]; $V_{(t)}$=volume of the remaining stand in current inventory [m^3 ha^{-1}]; $V_{removed}$=volume of removed stand in 2, 3, 4, 5 and 6 inventories [m^3 ha^{-1}]; inv=the number of inventory.

The periodic annual volume increment is calculated as the difference between the volumes of the growing stand in the current and previous inventories, including the volume of the removed stand ($V_{removed}$). The annual volume increment is found by dividing the numerator from the length of period between inventories (Equation 3-11).

$$PAI_V = \frac{V_{(t)} - V_{(t-p)} + V_{removed}}{p} \quad (3\text{-}11)$$

Where: PAI_V=periodic mean annual volume increment [m^3 ha^{-1}]; $V_{(t)}$=volume of the remaining stand in current inventory [m^3 ha^{-1}]; $V_{(t-p)}$=volume of the remaining stand in previous inventory [m^3 ha^{-1}]; $V_{removed}$=volume of the removed stand in analysed period [m^3 ha^{-1}]; p=the time between inventories in years.

The percentage of self-thinned trees from the periodic annual volume increment ($PAI_{removed}$) is calculated by dividing the volume of self-thinned trees that did not survive till the next inventory by the periodic annual volume increment (PAI_V).

3.6 Generation of database for modelling

3.6.1 Establishment of initial database

The initial database was formed by combining data from all six inventories. Data from present and previous inventories enable to estimate tree variables like tree periodic mean annual diameter increment (i_d), periodic mean annual tree basal area increment (i_{ba}) and periodic mean annual tree height increment (i_h) see Equations 3-12, 3-13 and 3-14.

$$i_d = \frac{d_{bh(t)} - d_{bh(t-p)}}{p} \quad (3\text{-}12) \qquad i_{ba} = \frac{ba_{(t)} - ba_{(t-p)}}{p} \quad (3\text{-}13) \qquad i_h = \frac{h_{(t)} - h_{(t-p)}}{p} \quad (3\text{-}14)$$

Where: i_d=periodic mean annual tree diameter increment in cm; $d_{bh(t)}$=tree diameter at breast height in current inventory in cm; $d_{bh(t-p)}$=tree diameter at breast height in previous inventory in cm; i_{ba}=periodic mean annual tree basal area increment [m^2]; $ba_{(t)}$=tree basal area in current inventory [m^2]; $ba_{(t-p)}$=tree basal area in previous inventory [m^2]; i_h=periodic mean annual tree height increment in m; $h_{(t)}$=tree height in current inventory in m; $h_{(t-p)}$=tree height in previous inventory in m; p=the length of period between inventories in years.

The equation to estimate volume of each tree (3-15) is presented in most tree mensuration or taxation books (THOMAS & BURKHART 1994, REPŠYS 1994, PHILIP 1998, KRAMER & AKCA 2002, HUSCH et al. 2003, WEST 2009) and is based on basal area, height and form factor.

$$v = \frac{\pi \cdot d_{bh}^{2} \cdot h \cdot f_s}{40000} \quad (3\text{-}15)$$

Where: v=tree stem volume [m^3]; d_{bh}=tree diameter at breast height in cm; f_s=form factor.

The most widely used Lithuanian form factor formula was developed by KULIEŠIS (1993) (see Equation 3-16).

$$f_s = 0.41097 + \frac{0.47997}{h} + \frac{1.02196}{d_{bh}} + \frac{0.12880}{d_{bh} \cdot h} + \frac{-2.84120}{d_{bh}^{2}} + \frac{6.3796}{d_{bh}^{2} \cdot h} \quad (3\text{-}16)$$

Where: f_s=form factor; d_{bh}=diameter at breast height in cm; h=tree height in m.

Additionally, crown length ratio was calculated from h and h_{cb} by applying Equation 3-17.

$$cr = \frac{(h - h_{cb})}{h} \cdot 100 \quad (3\text{-}17)$$

Where: cr=crown ratio %; h=tree height in m; h_{cb}=tree height to crown base in m.

Some variables, required for the final data base were calculated from existing data. Other data had to be modelled, descriptions of which appear in the following subsections.

3.6.2 Description of tree height-diameter curve

In all the PEPs, the measurement of h was only taken for sample trees. For other trees, h was modelled by applying d_{bh} and h nonlinear relationships. For this purpose, the formula proposed by MICHAILOFF (1943) was used (Equation 3-18).

$$h = 1.3 + e^{\left(\frac{a_0}{d_{bh}} + a_1\right)} \quad (3\text{-}18)$$

Where: h=tree height in m; d_{bh}=tree diameter at breast height in cm; a_0 and a_1=regression coefficients.

Height curves, resulting from a variety of measurements, must be plausible, steadily angling upward to the right of the Y axis and becoming flatter. Sometimes, due to measurement errors, curves cross each other. This study used JOHANN's (1990) method in order to smooth height curves from various inventories. As height function parameters for the 1998 and 2009 inventories existed for PEPs 85, 87, 91 and 92, height curves for 2004 were smoothed by interpolating the function coefficients a_0 and a_1 over MSA.

3.6.3 Description of tree crown length curves

All stands selected for modelling h_{cb} were divided into two groups: the older stands (PEPs 81-96) and the younger stands (201 and 206). In the younger stands, measurements of h_{cb} were only taken in the last inventory. Thus, for previous inventories, h_{cb} had to be modelled.
To calculate missing tree h_{cb} values in the first group, crown length (cl) as a difference between h and h_{cb} was initially calculated, after which the formula presented in Equation 3-19 completes the cl values. In the final step, missing h_{cb} values were calculated: h - cl.

$$cl = a_0 + a_1 \cdot h \quad (3\text{-}19)$$

Where: cl=crown length (h-h_{cb}) in m; h=tree height in m; h_{cb}=tree height to crown base in m; a_0, a_1=regression coefficients.

Also for the younger stands; in order to avoid the impact of stand density, the three largest trees from each PEP and from each inventory, which had exactly measured height to crown base data were selected. It was assumed that the three largest trees from PEPs 201 and 206, had had, at the time of the first inventory, crowns measuring the distance from the top of the trees to the ground. Thus, the h_{cb} values for such trees were set at 0.1 metres. This enabled relative crown length ratio ($cl_{relative}$) from h to be calculated using Equation 3-20. The model of $cl_{relative}$ from h was created by the means of linear regression analysis, by applying height logarithmic transformations and employing Equation 3-21. Relative values were selected because they are normally used when comparing objects of different sizes.

$$cl_{relative} = \frac{cl}{h} \quad (3\text{-}20) \qquad cl_{relative} = a_0 + a_1 \cdot \ln(h) \quad (3\text{-}21)$$

Where: $cl_{relative}$=relative crown length; cl=crown length in m; h=tree height in m; a_0, a_1=regression coefficients.

The h_{cb} could now be calculated using the Equation 3-22.

$$hcb = h - \left(cl_{relative} \cdot h\right) \quad (3\text{-}22)$$

Where: h_{cb}=tree height to crown base in m; $cl_{relative}$=relative crown length; h=tree height in m.

3.6.4 Development of tree crown width curves

Modelling of missing cw values for the last inventory is based on simple linear regression, with the independent value d_{bh} (Equation 3-23).

$$cw = a_0 + a_1 \cdot d_{bh} \tag{3-23}$$

Where: cw=crown width in m; d_{bh}=diameter at breast height in cm; a_0 and a_1=regression coefficients.

Modelling cw for earlier inventories, was more difficult, since no field measurements of cr_{rad} had been taken. Thus, multiple linear regression models had to be developed. The following parameters: d_{bh}, h, cl and MSA were selected as independent variables (Equation 3-24). The principles of multiple regression analysis will be described in subsection 3.10.2.

$$cw = a_0 + a_1 \cdot d_{bh} + a_2 \cdot h + a_3 \cdot cl + a_4 \cdot MSA \tag{3-24}$$

Where: cw=crown width in m; d_{bh}=diameter at breast height in cm; h=tree height in m; cl=crown length in m; MSA=mean stand age in years; a_0, a_1, a_2, a_3, a_4=regression coefficients.

Once the modelling of the cw missing values had been achieved, the data processing procedures had been completed allowing work to start on establishing the database.

3.6.5 Establishment of completed database

Completing the datasets for the database means that all the data, necessary for modelling, is available. All database variables can be classified into two groups: 1) tree level variables and 2) stand level variables. The first group comprises: tree diameter at breast height (d_{bh}), tree height (h), tree height to crown base (h_{cb}), crown width (cw), crown ratio (cr), tree height diameter ratio (h/d_{bh}), tree stem volume (v), periodic mean annual diameter, basal area and height increments (i_d), (i_{ba}) and (i_h). The second group comprises stand level variables all sourced from the remaining stand: mean stand age (MSA), the number of growing trees per hectare (N), quadratic mean diameter (D_q), mean stand height (H_q), stand top diameter (D_{100}), stand top height (H_{100}), basal area of remaining stand (BA) and standing volume (V). Additionally, variables that describe total stand like gross yield (GY) and periodic annual volume increment (PAI_V) were taken into account.

In completing the first inventory, the measurements taken for tree level variables for growing trees were 9500 for d_{bh}, 3100 for h and 1300 for h_{cb}. The accumulated aggregates of measurements for all inventories (1984, 1989, 1994, 1998, 2004 and 2009) were 38600 for d_{bh}, 11000 for h and 8000 for h_{cb}. Since the last inventory in 2009, 2450 measurements of cw have been taken and entered into the database. Since the beginning of investigation in 1984, 4900 trees from 9500 were eliminated by natural mortality.

3.7 Evaluation of complete database

3.7.1 Sample size and estimation of population's mean

While measuring d_{bh}, h, h_{cb} and cw in all the PEPs, only small samples of populations were taken. Equation 3-25 enables researchers to estimate with a high degree of accuracy the mean tree diameter at breast height ($\bar{D}$), mean tree height ($\bar{H}$), mean height to crown base ($\bar{H}_{CB}$) and mean tree crown width ($\bar{CW}$) measurements. This data, in turn, allows the researcher to decide if samples sufficiently represent all the population with predefined deviations (ČEKANAVIČIUS & MURAUSKAS 2000).

$$\delta = \frac{t_{SD}}{\sqrt{n}} \cdot \frac{S}{\bar{x}} \cdot 100 \qquad (3\text{-}25)$$

Where: δ=standard deviation of the mean %; t_{SD}=two tailed critical value of Student distribution t_{SD} 0.05 (≈1.96); S=sample's standard deviation; $\bar{x}$ =sample's mean value; n=number of observations.

The predefined standard deviation for $\bar{D}$, $\bar{H}$, $\bar{H}_{CB}$ and $\bar{CW}$ measurements was equal to 5%.

3.7.2 Estimation of potential site productivity

Site productivity index H_{AB} is equal to H_q at the base age (100 years). In the same manner, site productivity indexD_{AB} is equal to D_q at the base age. The values of H_{AB} and D_{AB} for any pine stand in given age are calculated by using Equations (3-26, 3-27) (KULIEŠIS 1993).

$$\frac{H_q - 1.3 - a_H(A-100)}{H_{AB} - 1.3} = 1 + 2.2191 \cdot 10^{-3}(A-100) - 3.7747 \cdot 10^{-5}(A-100)^2 + 4.0062 \cdot 10^{-7}(A-100)^3 \qquad (3\text{-}26)$$

$$\frac{D_q - a_D(A-100)}{D_{AB}} = 1 + 4.4824 \cdot 10^{-3}(A-100) - 3.6319 \cdot 10^{-5}(A-100)^2 + 1.8858 \cdot 10^{-7}(A-100)^3 \qquad (3\text{-}27)$$

Where: H_{AB}=site productivity index according to the mean stand height at the base age (100 years) in m; D_{AB}=site productivity index according to the stand mean diameter at base age (100 years) in cm; H_q=mean stand height in m; D_q=quadratic mean diameter in cm; a_H=0.034; a_D=0.031 - a_H and a_D - coefficients that describe height and diameter growth deviations from the standard curve.

While calculating site productivity indices for each inventory, it is possible to reveal the dynamics of H_{AB} or D_{AB} during the time-period and thus to evaluate increasing, stable or decreasing development patterns.

3.7.3 Estimation of relation between potential site productivity and forest yield

After analysing growth and yield in monocultures in Lithuania, KULIEŠIS (1989a) defined the most important forest formation types (FFT) as follows: accelerated, normal and slowed. This study used KULIEŠIS' FFT definitions to select the PEPs.

Stands were classified as *accelerated* FFT according to the following criteria: extremely early accumulation of large basal area, and standing volumes due to very high density, followed by drastic increases in intensity of self-thinning. Volume increment at about 60-70 years is equal or lower than natural mortality rates, thus it gets negative values (see Figure 3-9, Accel V). The stocking level (Equation 3-28) in accelerated FFT stands reaches its maximum at age 40 years and then constantly decreases.

The CI_{stand} (Equation 3-29) at the age of 40 years can reach values as high as 4. The $PAI_{removed}$ in accelerated FFT stands remains higher than 45% (KULIEŠIS 1989a). REINEKE (1933) gradient b_N (Equation 3-31) in $Y^{1\text{-}40}age$ is not lower than minus 0.8 and in $Prem^{81\text{-}100}age$ is not higher than minus 2.

Stands were classified as *normal* FFT according to the following criteria: intensive self-thinning, high growing energy during $Y^{1\text{-}40}age$, accumulated high growing volumes and significantly decreased volume increment in $Mat^{101\text{-}140}age$ (Figure 3-9).

The SL remains around the value of 1 and the CI_{stand} does not reaches higher values than 2.5 during the entire growth period. The share of $PAI_{removed}$ in *normal* FFT stands ranges between 25 and 45% (KULIEŠIS 1989a). REINEKE (1933) gradient b_N during all rotation ranges between minus 1 and minus 2.

Stands were classified as *slowed* FFT according to the following criteria: usually heavily thinned in early age, which ensures very intensive growth of trees and low rates of self-thinning during the entire rotation period (Figure 3-9). The SL, as well as CI_{stand}, reach values of 1 only in the end of the rotation. The $PAI_{removed}$ in these stands remains lower than 25% (KULIEŠIS 1989a). REINEKE (1933) gradient b_N in the $Y^{1\text{-}40}age$ stands is not higher than minus 2 and in the $Prem^{81\text{-}100}age$ stands is not lower than minus 0.8.

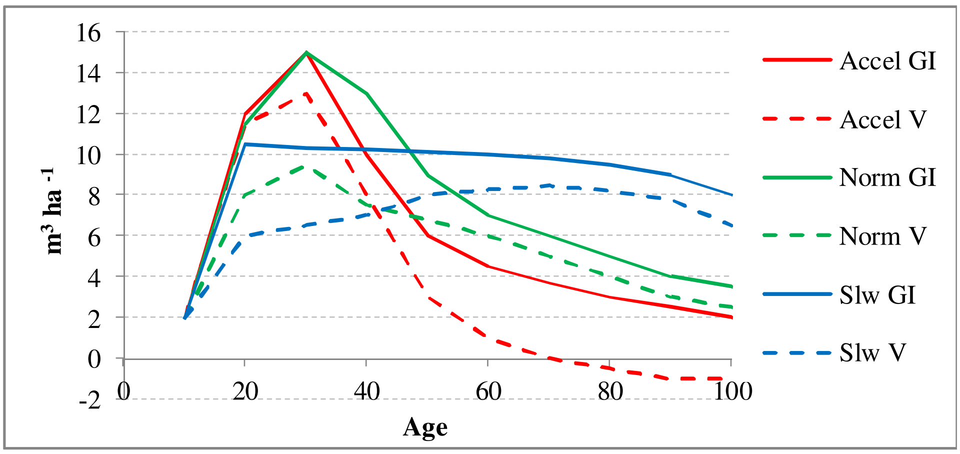


Figure 3-9: The dynamics of mean annual gross (GI) increment and mean annual accumulated volume (V) in pine stands of I bonitat under formation of stands by accelerated (Accel), normal (Norm) and slowed (Slw) types (KULIEŠIS 1989a).

When calculating the SL, standard volumes (volumes of stand with certain H_q when SL is equal to 1) for the PEPs are divided by the standing volume in the plot (Equation3-28).

$$SL = \frac{V}{-11.7778 + 11.077778 \cdot H_q + 0.255555 \cdot H_q^{\;2}} \tag{3-28}$$

Where: SL=stocking level; V=standing volume [m^3]; H_q=mean stand height in m.

The CI_{Stand} is estimated by dividing mean stand height (H_q) by tree growth area (q) - Equation 3-29 KULIEŠIS et al. 2010); q being the mean area occupied by a single tree per hectare, Equation 3-30, KULIEŠIS et al. 2010).

$$CI_{S\tan d} = \frac{H_q}{q} \tag{3-29}$$

$$q = \frac{10000}{N} \tag{3-30}$$

Where: CI_{Stand}=stand level competition index; H_q=mean stand height in m; N=the number of growing trees per ha; q=tree growth area.

The intensity of self-thinning in the stands was estimated by using REINEKE'S (1933) self-thinning rule (Equation 3-31). REINEKE (1933) assumed that the gradient b_N is equal to -1.605. This shows the intensity of tree number reduction when the mean diameter of a stand increases.

$$N = a_0 \cdot D_q^{\;b_N} \tag{3-31}$$

Where: N=the number of growing trees ha^{-1}; D_q=quadratic mean diameter in cm; b_N=the gradient of stand density rule proposed by Reineke; a_0=regression coefficient.

Estimation of relationship between potential site productivity and forest yield is achieved by comparing the potential site productivity, estimated according to the mean stand height at the base age H_{AB} with accumulated site productivity in selected PEPs. The age and the formation type of PEPs play important roles in this comparison (KULIEŠIS et al. 2010).

3.8 Analysis of competition for growing space

3.8.1 Competitor selection methods

The impact of competition on the mean annual increment in diameter, basal area and height (i_d, i_{ba}, i_h) was analysed by applying the methods for evaluating CIs, referred to in subsection 2.4.3 (using the *CroCom* analytical programme). In the distance dependent analysis, this study focuses only on angle gauge competitor selection methods. The search cone area is calculated by using the Equation 3-32.

$$dist_{ij} < \left(h_i - hcb_j\right) \cdot \tan\left(90 - \frac{\alpha}{2}\right)^{-1} \qquad (3\text{-}32)$$

Where: $dist_{ij}$=distance between competitor and target trees in m; h_i=height of target tree in m; h_{cbj}=height to crown base of competitor tree in m; α=cone opening angle in degrees.

When setting the search cone two important features should be taken into account. The first is the location of where the bottom of the inverse cone is set and the second is the opening angle of the search cone. This study focuses on three separate positions (see Figure 3-10) to set the inverse cone: a) at the height of the crown base, b) at the height of widest crown width, and c) at the stem base.

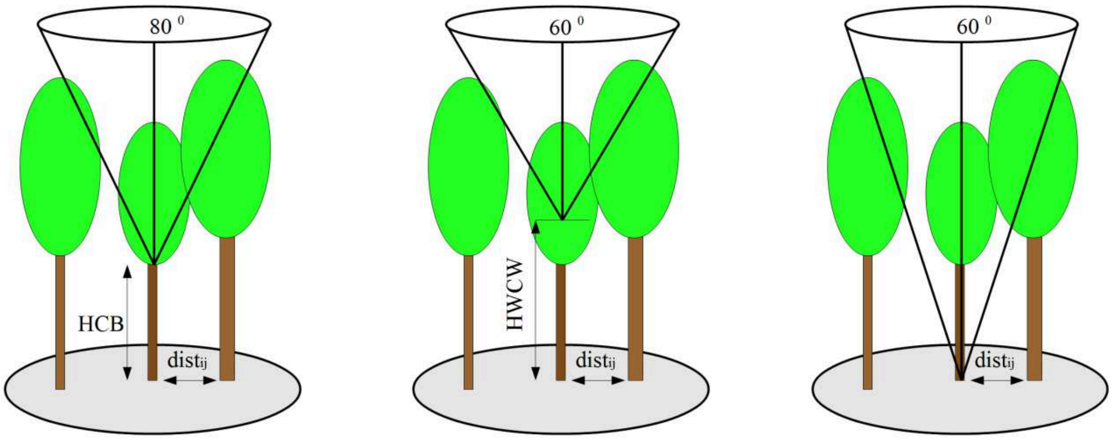


Figure 3-10: Competitor selection methods used in this study: (a) height to crown base 80 degrees (HCB 80); (b) height to widest crown width 60 degrees (HWCW 60); (c) stem base 60 degrees (SB 60); $dist_{ij}$=distance between target and competitor trees. Source: based on competitor selection methods proposed by (a) RÖHLE et al. 2004; (b) PRETZSCH 1995 and (c) BIGING & DOBBERTIN 1992.

The opening angle of the search cone is either 60 or 80 degrees. Trees that fall inside the search cone area are identified as competitors.

3.8.2 Equations to estimate competition between trees

In the context of estimating the strength of competition (see Table 3-3), two distance independent CIs, developed by WYKOFF et al. (1982) and HEGYI (1974) were selected for analysis. In addition, six distance dependent CIs proposed by HEGYI (1974), BIGING & DOBBERTIN (1992), PRETZSCH (1995), SCHRÖDER (2004) and NAGEL (1999) were taken into account. The indices developed by WYKOFF et al. (1982) and HEGYI (1974) are based on the relative sizes of tree diameters at breast height. The CIs developed by PRETZSCH (1995), SCHRÖDER (2004) and NAGEL (1999) and the two developed by BIGING and DOBBERTIN (1992), are based on the relative sizes of crown parameters such as cv, h_{ca} and v_{ca}.

Table 3-3: Researchers' and their formulae to estimate competition between trees.

	DEVELOPED BY	COMPETITION INDEX
Distance independent		
1.	WYKOFF et al. (1982)	$CI_1 = \sum_{j=1}^{Kj} BAL$
2.	HEGYI (1974)	$CI_2 = \sum_{j=1}^{Kj} \frac{d_{bh_j}}{d_{bh_i}}$
Distance dependent		
3.	HEGYI (1974)	$CI_3 = \sum_{j=1}^{Kj} \frac{d_{bh_j}}{d_{bh_i} \cdot (dist_{ij} + 1)}$
4.	BIGING & DOBBERTIN (1992)	$CI_4 = \sum_{j=1}^{Kj} \frac{h_{ca_j}^{(SH)}}{h_{ca_i}}$
5.	BIGING & DOBBERTIN (1992)	$CI_5 = \sum_{j=1}^{Kj} \frac{cv_j^{(SH)}}{cv_i}$ $cv = a_1 \cdot d_{bh}^{a_2} \cdot h^{a_3} \cdot cr^{a_4}$
6.	(PRETZSCH 1995)	$CI_6 = \sum_{j=1}^{Kj} \beta \frac{h_{ca_j}^{(HSCB_i)}}{h_{ca_i}}$
7.	SCHRÖDER (2004)	$CI_7 = \sum_{j=1}^{Kj} \frac{v_{ca_j}}{v_{ca_i} \cdot (dist_{ij} + 1)}$
8.	NAGEL (1999)	$CI_8 = \sum_{j=1}^{Kj} h_{ca_j}(HWCW_i)$

Where BAL=basal area of larger trees [cm^2]; K=number of trees per plot; i=subject tree; j=competitor(s); d_{bh}=diameter at breast height in cm; $dist_{ij}$=distance between competitor and target trees in m; h_{ca}=tree horizontal crown area [m^2]; cv=crown volume [m^3]; h=tree height in m; cr=tree crown ratio; SH=height of intersection of search cone and tree axis; β=gradient of straight line connecting base of search cone and top of competitor tree; v_{ca}=vertical crown area [m^2]; HSCB=height of search-cone base; HWCW=height of greatest crown width in 66% of subject tree height in m; a_1, a_2, a_3, a_4=regression coefficients.

Each of the three competitor selection methods (stem base; height to crown base and height to widest crown width) were combined with six methods for distance dependent estimations of strength of competition (n=3x6=18 CIs). Two additional distance independent CIs meant that a total of 20 CIs were chosen for more detailed statistical analysis (see Table 3-4).

Table 3-4. Combinations of competitor selection methods and competition indices analysed by the study.

No.	CI*	Type	Competitor Selection Method
1	CI_1	Distance Independent	None
2	CI_2	Distance Independent	None
3	CI_3	Distance Dependent	Height to Crown Base with opening angle 80^o (HCB80)
4	CI_4	Distance Dependent	Height to Crown Base with opening angle 80^o (HCB80)
5	CI_5	Distance Dependent	Height to Crown Base with opening angle 80^o (HCB80)
6	CI_6	Distance Dependent	Height to Crown Base with opening angle 80^o (HCB80)
7	CI_7	Distance Dependent	Height to Crown Base with opening angle 80^o (HCB80)
8	CI_8	Distance Dependent	Height to Crown Base with opening angle 80^o (HCB80)
9	CI_3	Distance Dependent	Height to Widest Crown Width with opening angle 60^o (HWCW 60)
10	CI_4	Distance Dependent	Height to Widest Crown Width with opening angle 60^o (HWCW 60)
11	CI_5	Distance Dependent	Height to Widest Crown Width with opening angle 60^o (HWCW 60)
12	CI_6	Distance Dependent	Height to Widest Crown Width with opening angle 60^o (HWCW 60)
13	CI_7	Distance Dependent	Height to Widest Crown Width with opening angle 60^o (HWCW 60)
14	CI_8	Distance Dependent	Height to Widest Crown Width with opening angle 60^o (HWCW 60)
15	CI_3	Distance Dependent	Stem base with opening angle 60^o (SB 60)
16	CI_4	Distance Dependent	Stem base with opening angle 60^o (SB 60)
17	CI_5	Distance Dependent	Stem base with opening angle 60^o (SB 60)
18	CI_6	Distance Dependent	Stem base with opening angle 60^o (SB 60)
19	CI_7	Distance Dependent	Stem base with opening angle 60^o (SB 60)
20	CI_8	Distance Dependent	Stem base with opening angle 60^o (SB 60)

* see Table 3-3 for explanations of CI_1-CI_8.

All competition indices were evaluated by applying partial correlation analysis. This method is fully described in the following subsection.

3.8.3 Partial methods to evaluate competition between trees

At each five-year interval, measurements of competition between trees in each PEP were assessed separately by partial correlation analysis. Measurements for trees growing at the edges of the PEPs were not included in this competition assessment. The reason for this is that competitor trees growing outside the PEPs were not measured and this absence of data had a negative effect on the competition values for trees growing at the edges. Consequently, buffer zones were established around the edges of the PEPs, 10m wide for PEPs 81-96, and 5m for PEPs 201 and 206. Only those trees growing inside the buffer zones were included in the competition analysis for both distance independent and distance dependent analysis.

Previous studies have shown that the correlations of the i_{ba} and i_h with the CIs were found to be non-linear (BIGING & DOBBERTIN 1992, SCHRÖDER 2004). So, the values of the CIs were transformed into a natural logarithmic form.

The partial correlation analysis was undertaken in three steps by using SCHRÖDER (2004) methods. First, using simple linear regression, i_{ba} or i_h were modelled from ba or h respectively (Equation 3-33). Second, the residuals between the measured and the modelled values were calculated (Equation 3-34). Logarithmic CIs were modelled from ba or from h (Equation 3-35) and the residuals between the measured and the modelled values were also recorded (Equation 3-36). Third, in order to show the strength of the relationships between the residuals, that were estimated in the first and second step, separately for ba or h, Pearson's correlation coefficient (r) was estimated (Equation 3-37, significance value of ≤0.05).

$$i_{ba} = a_0 + a_1 \cdot ba \quad (3\text{-}33) \qquad \mathrm{Re}\,s_1 = i_{ba} - i_{ba_{\mathrm{mod}}} \quad (3\text{-}34) \qquad \ln(CI_{1..8}) = a_0 + a_1 \cdot ba \quad (3\text{-}35)$$

$$\mathrm{Re}s_2 = \ln(CI_{1..8}) - \ln(CI_{1..8_{\mathrm{mod}}}) \quad (3\text{-}36) \qquad \mathrm{Re}\,s_1 = a_0 + a_1 \cdot \mathrm{Re}\,s_2 \quad (3\text{-}37)$$

Where: i_{ba}=periodic mean annual tree basal area increment [cm^2]; ba=tree basal area [cm^2]; $i_{ba_{mod}}$=modelled periodic annual basal area increment [cm^2]; ln=natural logarithm; $CI_{1..8}$=competition indices listed in Table 3-3; $C_{1..8_{mod}}$=modelled from basal area competition indices listed in Table 3-3; Res_1=residuals from periodic annual basal area increment and basal area model; Res_2=residuals from logarithmic CI and basal area model; a_0 and a_1=regression coefficients.

After estimating Pearson's correlation coefficient for all plots and for all measurements per subsequent measurement year, the mean partial correlation coefficients for each CI and selection method combination were calculated. In the same manner, the mean significances of correlation for each CI and the selection method combination were calculated (and labelled 'share of significant cases' in Table 4-6 and Table 4-7). The mean values for each CI were estimated (using SPSS) from 87 separate analyses of the 18 PEPs and from measurements of the six measurement years, which amounted to 1740 separate analysis.

3.8.4 The impact of competition on relative diameter and relative height increments

Once the most influential CIs for i_{ba} and i_h had been identified, it was necessary to show how the relative values of i_d change when competition between trees increases. Thus, all the sample trees were grouped according to the values of the most influential distance dependent CIs. The first group comprised trees with a CI value ≤2; the second group comprised trees with a CI value > 2 but ≤4. The last group comprised trees with a CI >24 but ≤26.

To show how relative i_h change with increasing competition, all the sample trees were grouped according to the values of the most influential distance dependent CIs (CI Group). The first, CI Group 1 comprised sample trees with a CI value ≤1; CI Group 2 - CI value of >1≤2; CI Group 3 - CI value of >2≤3; CI Group 4 - CI value of >3≤4; CI Group 5 - CI value of >4≤6; CI last group comprised sample trees with a CI value >58≤60. Next, for each CI

Group, the mean values of periodic mean annual tree diameter ($i_{\bar{d}}$) and tree height ($i_{\bar{h}}$) increments were calculated.

In the final step, regression analysis was conducted between mean CI values in each group and relative values (the ratio between mean value in group and mean maximum value of groups) of the $i_{\bar{d}}$ or $i_{\bar{h}}$ in each group respectively by fitting the appropriate regression curve.

3.9 Modelling tree growth

3.9.1 The comparison of Lithuanian and Saxony's yield tables

A comparison of the yield tables for Lithuania and Saxony reveals whether or not growth conditions of pine trees differs between Lithuania and eastern Germany. This analysis will show the potential of growth models used in Saxony to predict the growth of pine trees in Lithuania. If the yield tables show that growth conditions differs, growth models used in Saxony would have to be re-parameterised for Lithuanian growth conditions.

The Lithuanian yield tables analysed in this study are those described by KULIEŠIS (1993) and the yield tables for Saxony were taken from LEMBCKE et al. (2000). The comparison was achieved by evaluating the dynamics of five stand level variables: 1) mean stand height (H_q), 2) quadratic mean diameter (D_q), 3) quadratic mean diameter increment (ZD_q), 4) the number of growing trees ha^{-1} (N) and 5) yield levels produced by pine trees.

First stand level variable to be compared was H_q; specifically the dynamics of H_q over MSA. To reveal the impact of different productivity of sites, curves that cover site index H_{AB} in the range from 16 to 34m, with an increment step of 2m between curves, were analysed for Lithuania and Saxony.

The methodology of the analysis of stand level variable D_q was the same as for H_q, specifically evaluating the dynamics of D_q over MSA. Curves covering the same range of H_{AB} from 16 to 34m, with an increment step of 2m between curves, were analysed for Lithuania and Saxony.

The dynamics of ZD_q over the D_q and D_{AB} ratio provide good descriptions of differences of growth conditions. The D_q and D_{AB} ratio can be interpreted as a relative expression of MSA. The same 100 years base age was taken for Lithuania and Saxony. Interestingly, the D_q and D_{AB} ratio for pine stands at this age equals 1. For the comparison, data that represents average site indices (H_{AB}=27m for Lithuania and H_{AB}=26 m for Saxony), with a stocking level equal to 1 was taken into account. ZD_q values were calculated by putting required stand level variables into Equation 3-38.

$$ZD_q = \frac{D_{q(t+5)} - \sqrt{\dfrac{\left(D_{q(t)}{}^2 \cdot N_{(t)}\right) - \left(D_{qremoved(t)}{}^2 \cdot N_{removed(t)}\right)}{N_{(t+5)}}}}{5} \qquad (3\text{-}38)$$

Where: ZD_q=quadratic mean diameter increment in cm; $D_{q(t)}$=quadratic mean diameter of remaining stand at the time t in cm; $D_{q\ removed(t)}$=quadratic mean diameter of removed stand at the time t in cm; $N_{(t)}$=the number of growing trees at the time t, trees ha^{-1}; $N_{removed(t)}$=the number of self-thinned trees at the time t, trees ha^{-1}.

The dynamics of N over the age recorded in the yield tables for Lithuania and Saxony were analysed as well. Since density of pines is site dependent, the curves that show density over age in poor, average fertility and fertile stands are analysed by this study (H_{AB}=18m, 24m and 30m).

For the final comparison, the yield levels were compared. The yield levels are expressed by the dynamics of standing volume (V) over H_q. To visualise the yield levels in Lithuania, three curves of V over H_q, with H_{AB} values of 24m, 27m and 30m were presented and for yield levels in Saxony, four curves of V dynamics over H_q, with H_{AB} values equal to 24m, 26m, 28m and 30m.

3.9.2 Modelling diameter increment of trees

To avoid pseudo linearity that arises from linear logarithmic models, an original nonlinear periodic mean five year diameter increment (i_{d_5}) model was developed on the basis of the original model proposed by KULIEŠIS (1993, Equation 3-39).

To model the i_{d_5}, logarithmic, quadratic, cubic, power, growth and exponential functions were checked (SPSS 2008). In the pre-analysis, the power regression model had the best fit (highest coefficient of determination).

The D_q and D_{AB} ratio in power expression, added to the model, describes the influence of MSA and diameter growth conditions. The d_{bh} and D_q ratio, powered by D_q describes the position of a tree from the mean tree to the left and right side in the stand. The power of D_q modifies, d_{bh} and D_q according to MSA. The best of all the 20 CIs was chosen according to partial correlation analysis results. Since the CIs had value of 0, i.e. an undefined value when raised by a negative power, all the CI's values were increased by 1.

$$i_{d_5} = a_0 \cdot \left(\left(\frac{D_q}{D_{AB}} \right)^{a_1} \right) \cdot \left(\frac{d_{bh}}{D_q} \right)^{a_2 \cdot \left((D_q)^{a_3} \right)} \cdot \left((CI+1)^{a_4} \right) \quad (3\text{-}39)$$

Where: i_{d_5}=periodic mean five year diameter increment in m; d_{bh}=tree diameter at breast height in cm; D_q=quadratic mean diameter in cm; D_{AB}=quadratic mean diameter at a base age in cm; CI=distance dependent CI (Table 3-3, No 4); a_0, a_1, a_2, a_3, a_4=regression coefficients.

The constructed model was evaluated by means of nonlinear regression analysis. The principles or nonlinear regression analysis will be explained in sub section 3.10.3.

3.9.3 Modelling basal area increment of trees

The full description of a periodic mean five year basal area increment (i_{ba_5}) model used in the BWINPro-S simulator was first presented by NAGEL (1999, see also SCHRÖDER et al. 2007) and visualised in Table 3-5 below. The tree size in this model is expressed by the logarithmic crown surface area (csa). The age is also modified to logarithmic form. CI_4, used in this model, is described in Table 3-3. The csa is a function of crown radius (cr_{rad}) and crown length (cl). The cr_{rad} is calculated from crown width (cw), and cl is obtained from tree height (h) subtracting tree height to crown base (h_{cb}). Crown width is a function of d_{bh} and age. The h_{cb} is a function of d_{bh}, h and H_{100}.

In this study two i_{ba_5} models, original SCHRÖDER et al. (2007) and a new re-parameterised version of SCHRÖDER et al. (2007) will be compared in parallel. Firstly, using multiple regression analysis, the original SCHRÖDER et al. (2007) i_{ba_5} model developed for the Free State of Saxony will be checked against Lithuanian PEPs to reveal possible deviations when applied in Lithuania. Secondly, all regression parameters used in original SCHRÖDER et al. (2007) i_{ba_5} model will be estimated from PEPs located in Lithuania and as a result this model will be re-parameterised under Lithuanian growth conditions (re-parameterised version of SCHRÖDER et al. (2007)).

The original and re-parameterised versions of SCHRÖDER et al. (2007) i_{ba_5} model will be evaluated by linear regression analysis, defined in subsection 3.10.2.

Table 3-5: Periodic mean five year basal area increment model used in BWINPro-S.

	Model	Formula expression
1.	SCHRÖDER et al. (2007) i_{ba_5} model	$ln(i_{ba_5}) = a_0 + a_1 \cdot ln(csa) + a_2 \cdot ln(MSA) + a_3 \cdot CI_4 + a_4 \cdot \Delta CI_4 + \varepsilon_{rand}$ a_0=-6.332; a_1=0.9171; a_2=-0.6208; a_3=-0.1114 a_4=0.5638
2.	Crown surface area model	$csa = \frac{\pi \cdot cr_{rad}}{6 \cdot cl^2} \cdot \left[\left(4 \cdot cl^2 + cr_{rad}^2\right)^{\frac{3}{2}} - cr_{rad}^3 \right]$ $cl = h - h_{cb}$ $cr_{rad} = \frac{cw}{2}$
3.	Height to crown base model	$h_{cb} = h \cdot \left[1 - e^{-abs\left(a_0 + a_1 \frac{h}{d_{bh}} + a_2 \cdot d_{bh} + a_3 \cdot \ln(H_{100})\right)} \right]$ a_0=1.7838, a_1=-0.1943, a_2=0.0174, a_3=-1.0552
4.	Crown width model	$cw = \left(a_0 + a_1 \cdot d_{bh} + a_4 \cdot MSA + a_5 \cdot \ln\left(MSA^2\right)\right) \cdot \left[1 - e^{-\left(\frac{d_{bh}}{a_2}\right)^{a_3}} \right]$ a_0=3.1516; a_1=0.08283; a_2=18.5202; a_3=0.84159; a_4=0; a_5=0

Source: based on SCHRÖDER et al. (2007).

Where: i_{ba_5}=periodic mean five year basal area increment [m^2]; csa=crown surface area [m^2]; MSA=mean stand age in years; CI_4=distance dependent competition index (see Table 3-3); Δ CI_4=difference in competition index before and after thinning and mortality; ε_{rand}=random figure allowing for chance of variation; cl=crown length in m; cr_{rad}=crown radius in m; cw=crown width in m; d_{bh}=tree diameter at breast height in cm; h=tree height in m; h_{cb}=tree height to crown base in m; abs=function that returns absolute value of the number; H_{100}=stand top height in m; a_0, a_1, a_2, a_3, a_4, a_5=regression coefficients.

Logarithmic transformation introduces a systematic bias, thus in order to revert to the normal scale, the correction factor has to be applied to counteract this bias (SPRUGEL 1983). Equation 3-40 presents the formula used to calculate normal scale basal area increment values. Equation 3-41 estimates the transformation factor.

$$i_{ba_5} = e^{(a_0)} \cdot CSA^{a_1} \cdot MSA^{a_2} \cdot e^{(a_3 \cdot CI_4)} \cdot e^{\left(\frac{MRSE}{2}\right)} \quad (3\text{-}40) \qquad MRSE = \frac{\sum_{i=1}^{n} (Y_i - Y_i(X_i))^2}{n - k - 1} \quad (3\text{-}41)$$

Where: i_{ba_5}=periodic mean five year basal area increment [m^2]; csa=crown surface area [m^2]; MSA=mean stand age; CI_4=distance dependent competition index (Table 3-3); Y=dependent variable; X=independent variable; k=number of parameters in regression model; n=number of observations; MRSE=mean residual sum of squares of logarithmic model (transformation factor); a_0, a_1, a_2, a_3, a_4, a_5=regression coefficients.

3.9.4 Modelling height increment of trees

The modelling of the periodic mean five year height increment (i_{h_5}) was achieved by using SCHRÖDER (2004) model implemented in the BWINPro-S single tree level simulator (STLS). This model was fully re-parameterised for Lithuanian growth conditions.

SCHRÖDER (2004) model employs forest yield tables, where site index is estimated by stand top height (H_{100}) development over the MSA. Yet, this approach is not used in Lithuania by using National Forest Inventory (NFI) data. Thus, it was necessary to estimate H_{100} for Lithuanian forest yield tables (KULIEŠIS 1993).

Firstly, the height growth differences of Lithuanian and German pines were compared by evaluating mean stand height (H_q) development over MSA in Saxony and in Lithuania. Next, the H_{100} model, based on the data of the PEPs of this study, was developed by using various stand level variables, which were: stand top height (H_{100}), mean stand age (MSA), mean stand height and quadratic mean diameter at base age (H_{AB} and D_{AB}), the number of growing trees per hectare (N), mean stand height (H_q) and quadratic mean diameter (D_q). A correlation matrix is compiled of all these stand level variables to identify the most important independent variables for H_{100} modelling and to reveal possible autocorrelations between them. Additionally, logarithmic transformations of H_{100}, H_q and H_{AB} were tested as well. The developed H_{100} model was used to estimate H_{100} values for Lithuanian forest yield tables (KULIEŠIS 1993).

Further, modelling of height increment in SCHRÖDER (2004) model will be presented in more detail. Very important place in this method takes Equation 3-42 that is used to estimate H_{100}. Stand top height at base age (H_{100_AB}) used in the following equation is equal to the mean height of the 100 largest trees per hectare at the base age (100 years).

$$H_{100} = a_0 + a_1 \cdot \ln(MSA) + a_2 \cdot (\ln(MSA))^2 + a_3 \cdot H_{100\_AB} + a_4 \ln(MSA) \cdot H_{100\_AB} + a_5 \cdot (\ln(MSA))^3 \qquad (3\text{-}42)$$

Where: H_{100}=stand top height in m; MSA=mean stand age in years; H_{100_AB}=stand top height at base age (100 years) in m; a_0, a_1, a_2, a_3, a_4, a_5=regression coefficients.

At the next step in SCHRÖDER 2004, H_{100} is estimated for all PEPs and inventories by applying Equation 3-42. This enables the estimation of relative potential stand top height increment (${}^{i}H_{rel\_pot}$) for each PEP and inventory (Equation 3-43). The ${}^{i}H_{rel\_pot}$ shows the potential increase of each unit of H_{100} according to site productivity defined in forest yield tables.

$$^{i}\mathrm{H}_{\mathrm{rel\_pot}} = \frac{5\left(H_{100(t+p)} - H_{100(t)}\right)}{p \cdot H_{100(t)}} \tag{3-43}$$

Where: $^{i}H_{rel\_pot}$=relative potential stand top height increment; $H_{100(t)}$=stand top height in the beginning of simulation period in m; $H_{100(t+p)}$=stand top height in the end of simulation period in m; p=length of simulation period in years.

The relative height increment of each tree ($^{i}h_{rel}$) in SCHRÖDER (2004) model for the analysed growth period is estimated by using Equation 3-44.

$$^{i}h_{rel} = iH_{rel\_pot} + a_0\left(\frac{H_{100}}{h}\right)^{a_1} + \varepsilon_{rand} \tag{3-44}$$

Where: $^{i}h_{rel}$=relative tree height increment; $^{i}H_{rel\_pot}$=relative potential stand top height increment; H_{100}=stand top height in m; h=tree height in m; ε_{rand}=random figure allowing for chance of variation; a_0, a_1,=regression coefficients.

Finally, tree height at the end of simulation period ($h_{i(t+p)}$) is calculated from initial tree height ($h_{i(t)}$) by adding the product of tree height at the beginning of simulation period ($h_{i(t)}$) multiplied by the relative height increment of tree ($^{i}h_{rel}$) see Equation 3-45.

$$h_{(t+p)} = h_{(t)} + h_{(t)} \cdot^{i} h_{rel} = h_{(t)} \cdot \left(1 + i_{h_{rel}}\right) \tag{3-45}$$

Where: $h_{(t+p)}$=height of each individual tree in the end of simulation period in m; $h_{(t)}$=height of each individual tree at the beginning of simulation period in m; $^{i}h_{rel}$=relative tree height increment.

During the re-parameterisation all regression parameters used in SCHRÖDER (2004) model (Equations 3-42 and 3-44) will be estimated from PEPs located in Lithuania and as a result this model will be re-parameterised under Lithuanian growth conditions.
Models were evaluated by applying linear and nonlinear regression analysis (see subsections 3.10.2 and 3.10.3 respectively).

3.9.5 Modelling natural mortality of trees

The size of applied database. In the distance independent analysis, records for 1287 dead and 1305 growing trees suitable for analysis were available. To have equal number of growing and self-thinned trees, from total 18269 growing trees, systematically each 14th growing tree was selected for analysis.
Exclusion of the buffer zones in distance dependent analysis reduced the database to records for 654 dead and 640 growing trees.

Evaluation of BWINPro-S natural mortality model. The SCHRÖDER et al. (2007) natural mortality model used in the *BWINPro-S* simulator was checked against Lithuanian PEP's data to reveal possible deviations of the model when applied in Lithuania. Secondly, all regression parameters used in this model were estimated from PEPs located in Lithuania and model was re-parameterised under Lithuanian growth conditions. The SCHRÖDER et al. (2007) natural mortality model is presented in Equation 3-46, with the original coefficients a_0=0.3895, a_1=0, a_2=9.2627 and a_3=-2.2028.

$$F = \frac{1}{1+e^{\left(-\left(a_0 + a_1 \cdot d_{bh} + a_2 \cdot \frac{i_{ba_p}}{d_{bh}} + a_3 \cdot \frac{h}{d_{bh}}\right)\right)}} \tag{3-46}$$

Where: F=tree vitality indicating value; d_{bh}=tree diameter at breast height in cm; h=tree height in m; i_{ba_p}=periodic mean annual tree basal area increment in previous inventory period [cm^2]; a_0, a_1, a_2, a_3=regression coefficients.

Development of new natural mortality models. To develop new natural mortality models using tree size variables, 20 CIs (Table 3-3 and Table 3-4) and 8 stand level variables were applied. The tree size variables were: tree diameter at breast height (d_{bh}) and its transformations (natural logarithm of d_{bh}, d_{bh}^{-1}, d_{bh}^{2}), tree basal area (ba), tree height (h), tree height to crown base (h_{cb}), crown width (cw), crown ratio (cr), periodic mean annual tree diameter, basal area and height increments in previous inventory period (i_{d_p}, i_{ba_p}, i_{h_p}). Additionally, some derivative variables were checked, i.e. i_{ba_p}/d_{bh}, i_{h_p}/h, h/d_{bh}. Stand level variables used for the analysis were: the number of growing trees per hectare (N), mean stand age (MSA), mean stand height (H_q), quadratic mean diameter (D_q) top height (H_{100}), site productivity index (H_{AB}), basal area of remaining stand per hectare (BA) and standing volume per hectare (V). Additionally, one derivative variable d_{bh}/D_q was analysed as well.

When analysing each variable, univariate analysis was conducted and variables with a significance level lower than 0.25 were used in multivariable analysis (HOSMER & LEMESHOW 2000). Further, the importance of each variable included in the model was verified by applying Wald statistics and comparison of each estimated coefficient with the coefficient from the model that contains only this variable. Variables that do not contribute to the model based on these criteria were removed and new model was fit. At the last step, interactions among the variables used in the model were checked. Finally, each model was evaluated by the means of logistic regression analysis (subsection 3.10.4).

Mortality likelihood values were modelled by applying Equation 3-47. For this purpose, tree vitality values (F) that ranges from 0 to 1, were grouped into twenty classes (Class 1 - 0.95≤F<1, Class 2 - 0.90≤F<0.95…Class 20 - 0≤F<0.05) and mean mortality rates (%) observed in the field for each class was defined (SCHRÖDER et al. 2007). Next, mortality likelihood (ML) was modelled by using nonlinear regression analysis. Regression coefficients for the original SCHRÖDER et al. (2007) mortality likelihood function were equal to a_0=100, a_1=2.6711, a_2=1.4626.

$$ML = \frac{a_0}{e^{\left(a_1 \cdot F^{a_2}\right)}} \qquad (3\text{-}47)$$

Where: ML=mortality likelihood values %; F=tree vitality indicating value; a_0, a_1, a_2=regression coefficients.

At the final step, mortality likelihood values (ML) were compared with the equally distributed random values (MZ), (0≤MZ≤100) in order to simulate dichotomous decision about tree survival or death. If MZ>ML trees are classified as dead (DURSKY 1997).

3.10 The main methods of statistical analysis

3.10.1 Descriptive statistics

The main indicators for a population's descriptive statistics are: arithmetic mean (see Equation 3-48), sample's variance (see Equation 3-49) and sample's standard deviation (see Equation 3-50) (ČEKANAVIČIUS & MURAUSKAS 2000).

$$\overline{X} = \frac{\sum_{i=1}^{n} X_i}{n} \quad (3\text{-}48) \qquad S^2 = \frac{\sum_{i=1}^{n} (X_i - \overline{X})^2}{n-1} \quad (3\text{-}49) \qquad S = \sqrt{S^2} \quad (3\text{-}50)$$

Where: X=independent variable; $\bar{X}$ =arithmetic mean of independent variable; n=number of observations; S^2 =sample's variance; S=sample's standard deviation.

Simple linear correlation (r) describes the linear dependence between two unknown variables, for example X and Y. The r is calculated by using Equation 3-51 (ZAR 2010).

$$r = \frac{\sum XY - \frac{\sum X \sum Y}{n}}{\sqrt{\left(\sum X^2 - \frac{\left(\sum X\right)^2}{n}\right) \cdot \left(\sum Y^2 - \frac{\left(\sum Y\right)^2}{n}\right)}} \quad (3\text{-}51)$$

Where: r=simple linear correlation; X=independent variable; Y=dependent variable; n=number of observations.

Simple linear correlation values ranges from-1 to 1, ($-1 \le R \le 1$). The higher the absolute r value the stronger are correlations.

3.10.2 Methods of linear regression

Linear regression is used to define a dependent variable's values when values of independent variables are known (ZAR 2010). ČEKANAVIČIUS & MURAUSKAS (2002) describe the structure of a simple linear regression model (Equation 3-52), and ZAR (2010) presents a linear multiple regression model (Equation (3-53).

$$Y = a_0 + a_1 \cdot X + \varepsilon \quad (3\text{-}52) \qquad Y = a_0 + a_1 \cdot X_1 + a_2 \cdot X_2 + a_3 \cdot X_3 + \ldots + a_n \cdot X_n + \varepsilon \quad (3\text{-}53)$$

Where: Y=dependent variable; X_i, X_1, X_2, X_3, X_n=independent variables; ε=error of the estimate; a_0, a_1, a_2, a_3, a_n=regression coefficients.

To find simple linear regression coefficients the method of least squares is used (Equations 3-54, 3-55). To find linear multiple regression coefficients, the more complicated least squares method defined by ČEKANAVIČIUS & MURAUSKAS (2002) and ZAR (2010) is applied.

$$a_1 = \frac{\sum_{i=1}^{n} X_i Y_i - \left(\sum_{i=1}^{n} X_i \cdot \sum_{i=1}^{n} Y_i\right)/n}{\sum_{i=1}^{n} X_i^2 - \left(\sum_{i=1}^{n} X_i\right)^2 / n} \quad (3\text{-}54) \qquad a_0 = \overline{Y} - a_1 \cdot \overline{X} \quad (3\text{-}55)$$

Where: $\bar{X}$ =arithmetic mean of independent variable; $\overline{Y}$ =arithmetic mean of dependent variable; Y=dependent variable; X=independent variable; a_0, a_1=regression coefficients.

Once the regression model has been constructed, goodness of fit of the model, and the statistical significance of the estimated parameters need to be checked and whether or not regression assumptions are satisfied (in this study, done only for multiple linear regression models). The goodness of fit of the regression model was evaluated by estimating the coefficient of determination (R^2) see Equation 3-56 (ČEKANAVIČIUS & MURAUSKAS 2002).

$$R^2 = \frac{\sum_{i=1}^{n} \left(Y_i(X_i) - \overline{Y}\right)^2}{\sum_{i=1}^{n} \left(Y_i - \overline{Y}\right)^2} \quad (3\text{-}56)$$

Where: R^2=coefficient of determination; X=independent variable; Y=dependent variable; $\overline{Y}$ =arithmetic mean of dependent variable; n=number of observations.

Analysis of variance is used to answer, if at least one regression coefficient is not equal to 0 (Equations 3-57, 358 and 3-59). In the beginning of analysis two hypotheses are formulated: all regression coefficients are equal to 0 (H_0), and at least one regression coefficient is not equal to 0 (H_1). In order to answer this hypothesis, Fisher (F_{Fisher}) critical value is estimated. If $F_{Fisher}>F_\alpha(k, n\text{-}k\text{-}1)$ the null hypothesis is rejected and if $F_{Fisher}<F_\alpha(k, n\text{-}k\text{-}1)$ the null hypothesis is accepted. $F_\alpha(k, n\text{-}k\text{-}1)$ is Fisher's distribution's with k (number of regression parameters) and (n-k-1) decisions of freedom, α critical value (ČEKANAVIČIUS & MURAUSKAS 2002).

$$F_{Fisher} = \frac{MRSS}{MRSE} \quad (3\text{-}57) \quad MRSS = \frac{\sum_{i=1}^{n} \left(Y_i(X_i) - \overline{Y}\right)^2}{k} \quad (3\text{-}58) \quad MRSE = \frac{\sum_{i=1}^{n} \left(Y_i - Y_i(X_i)\right)^2}{n-k-1} \quad (3\text{-}59)$$

Where: F_{Fisher}=Fisher's distribution's critical value; $\overline{Y}$ =arithmetic mean of dependent variable; Y=dependent variable; X=independent variable; k=number of parameters in regression model; n=number of observations; MRSE=mean residual sum of squares; MRSS=mean regression sum of squares.

Student's critical value (t_{SD}) is used to estimate statistical significance of each coefficient in the multiple regression models. For each regression coefficient, two hypotheses are formulated: the regression coefficient is equal to 0 (H_0) and the regression coefficient is not equal to 0 (H_1). The null hypothesis is rejected if $|t_{SD}|>t_{SD\ \alpha/2}(n\text{-}k\text{-}1)$ and it is accepted if $|t_{SD}|<t_{SD\ \alpha/2}(n\text{-}k\text{-}1)$. In case of two independent variables t_{SD} is estimated by Equation 3-60.

$$t_{ST} = a_1 \sqrt{\frac{(n-1) \cdot S^2 \cdot (1-r^2)}{MRSE}} \tag{3-60}$$

Where: t_{SD}=two tailed critical value of Student distribution; a_1=analysed regression coefficient; n=number of observations; S^2=variance of independent variable that impact to regression is defined by coefficient a_1; r=empirical correlation between two independent variables; MRSE=mean residual sum of squares.

ZAR (2010) defines regression assumptions that have to be satisfied: 1) the values of the independent variables are random, independent from each other and come from a sampled population; 2) there is, for any combination of independent variables, a normal distribution of dependent variables; 3) there is homogeneity of variances of the dependent variable in the whole range of independent variables; and 4) the measurements were obtained with no errors or negligible errors compared to the magnitude of the dependent variable.

The second regression assumption (2) was evaluated by plotting quintile-quintile (Q-Q) probability plots, which is a graphical method of comparing probability distributions by plotting their quintiles on the abscissa (x-axis) and ordinate (y-axis) axes (ZAR 2010). To produce Q-Q plots in this study, model residuals were first sorted in descending order. Secondly, each residual was ranked; thirdly, rank proportions for each residual were estimated from residual rank by subtracting 0.5 and dividing it by the highest rank; fourthly (and finally), rank based-z scores were calculated by applying Excel 2010 function NORMSINV. Having values of residuals and rank based-z scores, enable the production of Q-Q plots by plotting values of residuals on abscissa (x-axis) axis and values of rank based-z scores on ordinate (y-axis) axis.

The homogeneity of variance of the model's residuals was evaluated by plotting modelled values on the abscissa (x-axis) axis and model's residuals on the ordinate (y-axis) axis. To reveal if model's residuals were equally distributed throughout the range of modelled values, Loess nonparametric regression was used (PELTIER 2013). The alpha value of this regression was equal to 0.33.

The outliers in the regression model were identified by using values of standardized residuals (Equation 3-61). The measurement is called outlier if the value of standardized residuals (res_{ST}) is higher than 3 or lower than -3 (ČEKANAVIČIUS & MURAUSKAS 2002).

$$res_{ST} = \frac{res - \overline{res}}{S} \tag{3-61}$$

Where: res_{ST}=standardized residuals; $\overline{res}$ =arithmetic mean of residuals; S=sample's standard deviation.

To estimate possible multicollinearity between independent variables in multiple regression models, the variance inflation factor (VIF) statistics for each variable in the model was calculated (Equation 3-62). The coefficient of determination (R_1^2) for the analysed independent variable is estimated by regression analysis, putting the analysed variable on the left side and all the other independent variables on the right side of the equation. A value of less than 4 of the VIF indicates no multicollinearity between the analysed variables (ČEKANAVIČIUS & MURAUSKAS 2002).

$$VIF = \frac{1}{1 - R_1^2} \tag{3-62}$$

Where: VIF=variance inflation factor statistics for selected variable; R_1^2=coefficient of determination between analysed and all other independent variables.

To conclude, simple linear regression models were evaluated by estimating goodness of fit with the coefficient of determination and the statistical significance of regression coefficients. For linear multiple regression models, the additionally statistical significance of the estimated parameters as well as the regression assumptions were checked. The latter was evaluated with normal Q-Q plots and the residual distribution over the modelled values plots. Multicollinearity of independent variables was estimated by calculating VIF statistics.

3.10.3 Methods of nonlinear regression

If the relationship between dependent and independent variables is not linear, nonlinear regression models are used. Simple nonlinear regression models could be expressed by the following Equation 3-63 (BATES & WATTS 1988).

$$Y = f(X, \theta) + \varepsilon \tag{3-63}$$

Where: Y=dependent variable; X=independent variable; f=nonlinear function of the parameter θ; ε=error of the estimate.

This study used mainly logarithmic and exponential nonlinear regression models. The parameters in nonlinear regression models are found by using Gauss-Newton maximum likelihood methods. Models with several independent variables are called nonlinear multiple regression models (BATES & WATTS 1988).

Once the regression model has been constructed, it is necessary to evaluate it. For this purpose, goodness of fit was estimated for simple and multiple nonlinear regression models and regression assumptions were checked only for multiple nonlinear regression models. Since only pseudo statistical significance of regression coefficients is obtained in nonlinear regression models (ZAR 2010), this parameter was not estimated.

Goodness of fit of the nonlinear regression model was evaluated by estimating the adjusted coefficient of determination (R^2_{adj}) with Equation (3-64), see ZAR (2010).

$$R^2_{adj} = 1 - \frac{RSS}{CSS} = \frac{RSS}{RSS - n} \qquad (3\text{-}64) \qquad RSS = \sum_{i=1}^{n} \left(Y_i - Y(X_i)\right)^2 \qquad (3\text{-}65)$$

$$CSS = RSS - \frac{RSS^2}{n} = \frac{RSS \cdot (n - RSS)}{n} \qquad (3\text{-}66)$$

Where: R^2_{adj}=adjusted coefficient of determination; RSS=residual sum of squares; CSS=corrected sum of squares; Y=dependent variable; X=independent variable; n=number of observations.

Regression assumptions were checked by producing Q-Q plots and checking homogeneity of the variance of the model's residuals (see subsection 3.10.2).

To find the outliers, derivatives were estimated (BATES & WATTS 1988). Linear regression methods between dependent variable and derivatives as independent variables were used to find the outliers (SPSS 2008). The value of regression standardized residuals higher than 3 or lower than -3 identified the measurement as an outlier.

Possible multicollinearity of independent variables, used in multiple nonlinear regression models was estimated by producing correlation matrices of parameter estimates.

To conclude, simple nonlinear regression models were evaluated by estimating goodness of fit with adjusted coefficient of determination. For multiple nonlinear regression models, additionally, regression assumptions were checked by producing normal Q-Q plots and homogeneity of variance of model's residuals. Multicollinearity of independent variables used in the models was estimated by producing correlation matrices of parameter estimates.

3.10.4 Methods of logistic regression

The multiple logistic regression methods were used to estimate the probability of natural tree mortality. The general logistic regression model is specified in the Equation 3-67 (HOSMER & LEMESHOW 2000).

$$\pi(X) = \frac{e^{(a_0 + a_1 \cdot X_1 + a_2 \cdot X_2 + a_n \cdot X_n)}}{1 + e^{(a_0 + a_1 \cdot X_1 + a_2 \cdot X_2 + a_n \cdot X_n)}} \qquad (3\text{-}67)$$

Where: $\pi(X)$=conditional probability; X_1, X_2, X_n=independent variables; a_0, a_1, a_2, a_n=regression coefficients.

The parameters of multiple logistic regression models are found by applying maximum likelihood methods. After a meaningful number of iterations, the parameters are selected if the value of Equation 3-68 is maximised (ČEKANAVIČIUS & MURAUSKAS 2002).

$$L = \int_{n}^{Y_n=1} \pi(X) \int_{n}^{Y_n=0} (1-\pi(X)) \tag{3-68}$$

Where: L=value of the maximum likelihood function; $\pi(X)$=conditional probability; Y=dependent variable; n=number of observations.

If the value of conditional probability ($\pi(X)$) is higher than 0.5 (cut point), the dependent variable is classified as 1, if it is lower than 0.5 it is classified as 0.

The defined logistic regression model is evaluated by checking the statistical significance of the model and its estimated parameters, and by evaluating all measures of goodness of fit.

The logistic model's statistical significance is evaluated by using Pearson's chi square statistics that is an analog of regression ANOVA. To solve Pearson's chi square statistics two hypotheses are formulated: 1) the H_0 hypothesis that all independent variables are equal to zero and 2) the H_1 hypothesis that at least one variable is not equal to zero. The H_0 hypothesis is denied if $X^2 > X^2_{\alpha}(k)$ and H_0 is accepted if $X^2 \leq X^2_{\alpha}(k)$. The formula $X^2_{\alpha}(k)$ is the value of Pearson's chi square statistics with k decisions of freedom at α critical value. If p value is less than α (0.05), the H_0 hypothesis is rejected (ČEKANAVIČIUS & MURAUSKAS 2002). Pearson's chi square statistical criterion is calculated by using Equation 3-69.

$$X^2 = -2\ln L(\tilde{a},0) + 2\ln L(\hat{a},\hat{b}) \tag{3-69}$$

Where: X^2=value of Pearson's chi square statistics; $L(\tilde{a},0)$=value of the maximum likelihood function of logistic regression model where all a_n=0; $L(\hat{a},\hat{b})$=value of the maximum likelihood function of analysed model with specified coefficients a_1 and a_2.

Wald statistics, the analogue of Student's statistics in multilinear regression analysis, is used to evaluate statistical significance of each of the model's parameters (Equation 3-70). For each regression coefficient two hypotheses are formulated: 1) the H_0 hypothesis that regression coefficient is equal to 0, and 2) the H_1 hypothesis that regression coefficient is not equal to 0. The H_1 hypothesis is proved if Wald's statistical significance's value is lower than 0.05. Otherwise the H_0 hypothesis is accepted (ČEKANAVIČIUS & MURAUSKAS 2002).

$$W = \frac{a_n}{S_{a_n}} \tag{3-70}$$

Where: W=Wald statistics; a_n=regression coefficients; S_{a_n}=standard deviation of coefficient a_n.

Goodness of fit of logistic regression models was evaluated by estimating the following parameters: log likelihood function values, Cox-Snell and Nagelkerkle's coefficients of determination, classification tables and areas under the ROC curves.

When comparing Log likelihood function values, the smaller the Log likelihood function value the better adapted is the model. Logistic regression analysis employs several coefficients of determination. This study practiced Cox-Snell and Nagelkerkle's coefficients of determination (Equations 3-71 and 3-72, ČEKANAVIČIUS & MURAUSKAS 2002).

$$r^2_N = \frac{r^2_{CS}}{1-\left(L(\tilde{a},0)\right)^{\frac{2}{n}}} \qquad (3\text{-}71)$$

$$r^2_{CS} = 1-\left(\frac{L(\tilde{a},0)}{L(\hat{a},\hat{b})}\right)^{\frac{2}{n}} \qquad (3\text{-}72)$$

Where: r^2_{CS} and r^2_N=Cox-Snell and Nagelkerkle's coefficients of determination; $L(\tilde{a},0)$=value of the maximum likelihood function of logistic regression model where all $a_n=0$; $L(\hat{a},\hat{b})$=value of the maximum likelihood function of analysed model with specified coefficients $a_1$and a_2; n=number of observations.

Classification tables summarise the results of the fitted logistic regression model. The classification table is a simple matrix of estimated 1 and 0 dichotomous variables and estimated from the logistic probabilities of correctly classified 1 and 0 values. Next, separately, the percentage of correctly classified 1 values, correctly classified 0 values and total correct classification is presented. Normally, total correct classification cannot be lower than 50% (ČEKANAVIČIUS & MURAUSKAS 2002).

The final evaluation of the model was achieved by drawing Receiver Operating Characteristic (ROC) curves and evaluating the area under them. HOSMER & LEMESHOW (2000) explain that the ROC curve is the plot of sensitivity (Equation 3-73) versus 1- specificity (Equation 3-74), over all possible cut points (from 0 to 1). As a general rule, a ROC area more than 0.7 is considered as acceptable discrimination (HOSMER & LEMESHOW 2000).

$$sensitivity = \frac{y_{correct}(1)}{y_{total}(1)} \qquad (3\text{-}73)$$

$$specificity = \frac{y_{correct}(0)}{y_{total}(0)} \qquad (3\text{-}74)$$

Where: $y_{correct}(0)$=correctly classified 0 values; $y_{total}(0)$=the sum of correctly and not correctly classified 0 values; $y_{correct}(1)$=correctly classified 1 values; $y_{total}(1)$=the sum of correctly and not correctly classified 1 values.

To conclude, multiple logistic regression models were evaluated by estimating the statistical significance of the model with Pearson's chi square statistics and the statistical significance of model's parameters with Wald statistics. Next, goodness of fit was estimated using log likelihood function values, Cox-Snell and Nagelkerkle's coefficients of determination, classification tables and ROC curves.

3.11 Methods used for model validation

The re-parameterised SCHRÖDER et al. (2007) basal area increment and SCHRÖDER (2004) height increment models were validated using data of validation plots 5 and 7. The initial data from validation plots 5 and 7 was placed into the BWINPro-S single tree level simulator with re-parameterised models' coefficients and simulations of trees growth were made. For plot 5, five simulations with five year intervals were implemented (from 1983 to 2008) and for plot 7 five simulations with five year intervals and four simulations with a one year interval were carried out (from 1983 to 2012).

The simulation results were evaluated using the methods of VANCLAY (1994) and PRETZSCH (2009). At the first step, modelled values were plotted against measured values, and model residuals were plotted against modelled values. Finally, bias, relative bias, precision, relative precision, accuracy and relative accuracy were estimated to compare modelled and measured values for re-parameterised models using the Equations presented below.

$$\bar{e} = \frac{\sum_{i=1}^{n}\left(x_{simulated} - x_{observed}\right)}{n} \quad (3\text{-}75) \qquad \bar{e}_{\%} = \frac{\bar{e}}{\overline{X}_{observed}} \cdot 100 \quad (3\text{-}76)$$

$$S_e = \sqrt{\frac{\sum_{i=1}^{n}\left(x_{simulated} - \bar{e} - x_{observed}\right)^2}{n-1}} \quad (3\text{-}77) \qquad S_{e\%} = \frac{S_e}{\overline{X}_{observed}} \cdot 100 \quad (3\text{-}78)$$

$$m_x = \sqrt{\frac{\sum_{i=1}^{n}\left(x_{simulated} - x_{observed}\right)^2}{n-1}} \quad (3\text{-}79) \qquad m_{x\%} = \frac{m_x}{\overline{X}_{observed}} \cdot 100 \quad (3\text{-}80)$$

Where: $\bar{e}$=bias; $\bar{e}_{\%}$=relative bias; S_e=precision; $S_{e\%}$=relative precision; m_x=accuracy; $m_{x\%}$=relative accuracy; $x_{simulated}$=values of simulation runs; $x_{observed}$=observed values; $\bar{X}_{observed}$=arithmetic mean of observed value; n=number of observations.

Described validation procedure will help to clarify if re-parameterised models produce reliable predictions on the basis of independent data.

3.12 Programs used in the research

While performing research, mathematical calculations and statistical analysis was achieved employing computer based software. Single tree growth simulations were done using the simulator BWINPro-S (RÖHLE et al. 2004). Distance dependent CIs were calculated employing the program CROCOM developed by MÜNDER (2005). Statistical analysis was done by using the statistical package SPSS Statistics 17, Release 17.0.0 (August 23, 2008). Finally, Microsoft Office 2010 programme was used for graphs and writing the text.

4 RESULTS

4.1 Evaluation of complete database

4.1.1 Sample size and estimation of population's mean

The ability of the sample size, to represent the Lithuania's pine tree population, was estimated by evaluating precision (Equation 3-25) of the mean tree diameter at breast height ($\bar{D}$), mean tree height ($\bar{H}$), mean height to crown base ($\bar{H}_{CB}$) and mean tree crown width ($\bar{CW}$) measurements. Since the precision between inventories varies only slightly, results from last inventory will be discussed in detail (Figure 4-1). Results from other inventories are presented in Appendix 1.

In the last inventory (2009), the lowest standard deviation of $\bar{D}$ was found for PEP 201 (13.2±0.25cm) and 206 (9.1±0.28cm), see Figure 4-1a. The highest standard deviation of $\bar{D}$ was found in PEP 82 (26.6±1.6 cm), which was the only PEP with standard deviation of $\bar{D}$ higher than the predefined 5%. Mean standard deviation of $\bar{D}$ in all PEPs was 3.41% (Appendix 1).

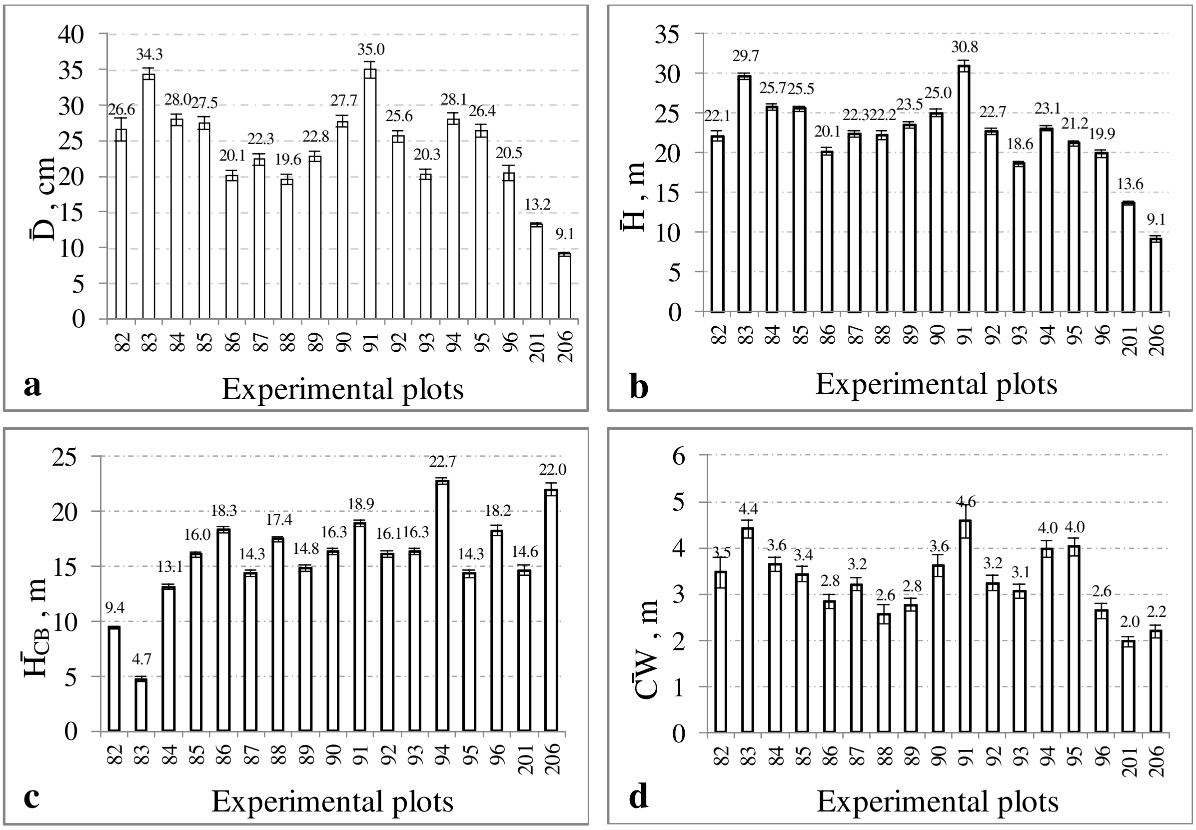


Figure 4-1: Estimation of standard deviation in last inventory (2009): (a) mean tree diameter at breast height ($\bar{D}$) measurements, (b) mean tree height ($\bar{H}$) measurements, (c) mean height to crown base measurements ($\bar{H}_{CB}$) and (d) mean crown width measurements ($\bar{CW}$).

The lowest standard deviation of $\bar{H}$ was obtained for PEP 201 (13.6±0.23m) see Figure 4-1b and the highest PEP 91 (30.8±0.72m). In none of the PEPs was the standard deviation of $\bar{H}$ higher than the predefined 5%. The mean standard deviation of $\bar{H}$ in all PEPs was equal to 2.1% (Appendix 1). The results of standard deviation of $\bar{H}_{CB}$ analysis revealed quite similar patterns as for the standard deviation of $\bar{H}$ (Figure 4-1c) with the lowest standard deviations in PEP 201 (9.4±0.14m) and the highest PEP 91 (22.0±0.6m). The standard deviation of $\bar{H}_{CB}$ in all PEPs was not higher than 5% and the mean standard deviation of $\bar{H}_{CB}$ in all PEPS was 1.98% (Appendix 1).

Crown width measurements were not as precise as other measurements (Figure 4-1d). Standard deviation of $\bar{CW}$ was lower than 5% (PEPs 83, 84, 85, 87, 92, 94 and 95) higher than 5% but lower than 7% (PEPs 86, 89, 90, 93, 96, 201 and 206) and higher than 7% but less than 10% (PEPs 82, 88 and 91). Standard deviation of $\bar{CW}$, varied from 2.0±0.11m (PEP 201) to 4.6±0.37m (PEP 91). Mean standard deviation of $\bar{CW}$ in all PEPs was 5.82% (Appendix 1).

Mean standard deviation of $\bar{D}$ in all PEPs for previous inventories was not higher than 3.5%. Then, standard deviation of $\bar{H}$ in all PEPs for previous inventories was not higher than 3.18% and mean standard deviation of $\bar{H}_{CB}$ in all PEPs for previous inventories was not higher than 2.83% (Appendix 1).

To conclude, the selected sample of 18 PEPs and number of performed measurements is sufficient and clearly represents the pine populations in the analysed areas with the required predefined precision.

4.1.2 Estimation of potential site productivity

Potential site productivity was estimated by mean height in at the base age (H_{AB}). Site potential productivity in the PEPs varied from 19 to 33 metres (Figure 4-2). The difference between the most and least fertile sites estimated by H_{AB} difference was 14 metres. All 18 PEPs can, according to potential site productivity index, be categorised into one of four fertile potentiality groups according to H_{AB} index and interval. Thus Group (i) consists of stands with H_{AB} - index of 22m and interval of 20.5-23.5m - (PEPs 86, 93, 95 and 96) represent the potentially moderately productive sites; Group (ii) with H_{AB} - index of 25m and interval of 23.5-26.5m - (PEPs 81, 87, 90, 92, 94) represent the potentially fertile sites; Group (iii) with H_{AB} - index of 28m and interval of 26.5-29.5m - (PEPs 85, 88, 89, 201 and 206) represent the potentially high productive sites and Group (iv) with H_{AB} - index of 31m and interval of 29.5-

32.5m - (PEPs 82, 83, 84 and 91) represents the potentially the highest productive sites. First two groups (22 and 25 metres) could be joined to potentially moderately productive and the other two groups (28 and 31metres) to potentially high productive clusters (Figure 4-2, marked by green dashed line and blue line respectively).

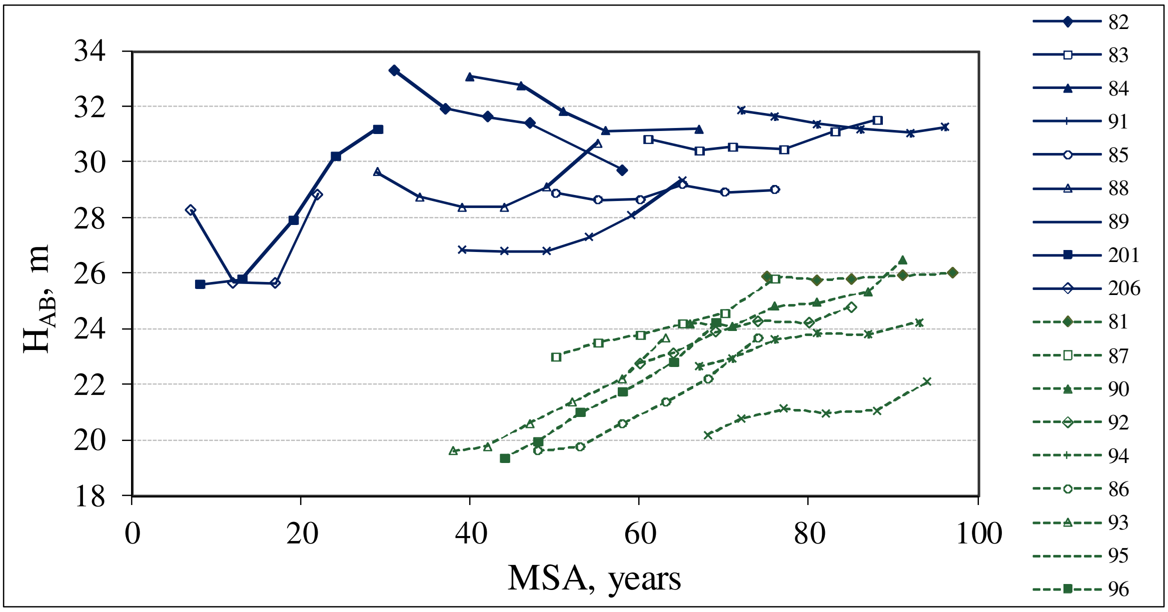


Figure 4-2: The dynamics of site productivity index H_{AB}, estimated by height growth on PEPs. Blue line represents potentially high productive and green dashed line show potentially moderately productive clusters. MSA=mean stand age in years.

Figure 4-2 also reveals the dynamics of H_{AB} over mean stand age (MSA) during 25 year inventory period, particularly of decreasing, stable and increasing H_{AB} trends. Decreasing trends were observed in high potentially productive PEPs 82, 84 and 91; increasing trends were found in least potentially productive PEPs 86, 87, 88, 89, 90, 92, 93, 94, 95, 96, 201 and 206. Stable trends occurred in a few plots, such as PEPs 81, 83 and 85.

Supplementary analysis of H_{AB} dynamics revealed a correlation between increasing height growth and age increase in potentially moderately productive clusters. In the potentially high productive cluster H_{AB} tree height growth is quite stable with only a few small random positive and negative growth deviations were recorded. The height growth fluctuations in PEPs 201 and 206 showed that height growth was not yet stabilized.

The Site productivity index based on mean diameter at base age (D_{AB}) in the PEPs varied from 21 to 43 centimetres (Figure 4-3). All 18 PEPs can, according to this index, be categorised into another four groups. Thus Group (i) consists of stands with D_{AB} – index of 25cm and interval of 22.5-27.5cm – represents the potentially moderately productive sites (PEPS 86, 93, 95, 96); Group (ii) consists of stands with D_{AB} – index of 30cm and interval of 27.5-32.5cm – represents the potentially fertile sites (81, 87, 88, 89, 90, 92, 94); Group (iii) consists of stands with D_{AB} – index of 35cm and interval of 32.5-37.5cm – represents the potentially higher productive sites (PEPS 83, 84, 85, 91); and Group (iv) consists of stands with D_{AB} – index of 40cm and interval of 37.5-42.5cm – represents the potentially the highest productive sites (PEPS 82, 201, 206). First two groups (25 and 30 centimetres) could be joined to potentially moderately productive and the other two groups (35 and 40 centimetres) to potentially high productive clusters (Figure 4-3, marked by green and blue colours).

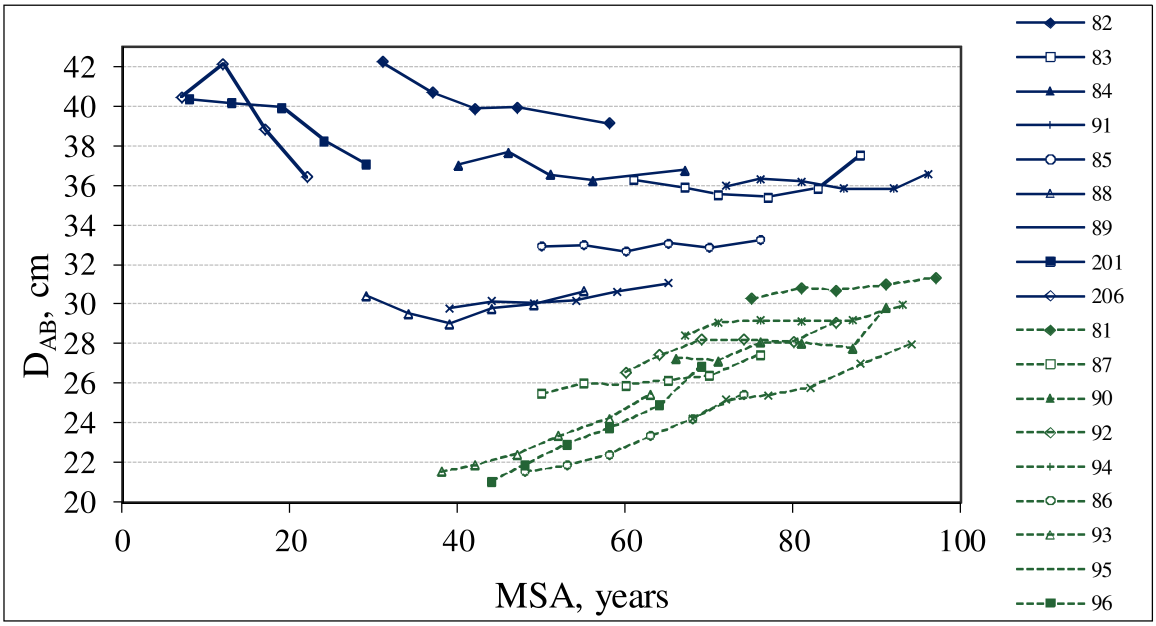


Figure 4-3: The Dynamics of D_{AB} (site productivity index) estimated by diameter growth on the permanent experimental plots. Blue line represents potentially high productive and green dashed line show potentially moderately productive clusters. MSA=mean stand age in years.

Decreasing trends in D_{AB} occurred in PEPs 82, 201 and 206; increasing trends in PEPs 86, 87, 90, 92, 94, 95 and 96 and stable trends in PEPs 81, 83, 84, 85, 88, 89, 91 and 93 (Figure 4-3). Site productivity according to H_{AB} does not always correspond with site productivity estimated by D_{AB}, indeed site productivity estimated by D_{AB} could differ by 2-3 groups from that estimated by H_{AB}. Significantly high differences were observed in Group (iii) H_{AB} of 28cm for PEPs 85, 88, 89, 201 and 206, whereas the D_{AB} values for this group vary from 30 to 40cm. Increases in D_{AB} during the 25 year inventory period were observed in the PEPs with smallest D_{AB} values (PEPs 88 and 89). By contrast, decreases in D_{AB} were observed in PEPs with the highest D_{AB} (PEPs 201 and 206). All PEPs that have D_{AB} values from 21 to 31cm, are characterised by faster tree height and tree diameter growth with increasing age, indicated by increases of D_{AB} values by 2-4cm in 25 years. However, deeper analysis revealed significant inconsistencies of trees diameter and height growth in these stands, for example PEP 95 has the lowest H_{AB} value at 20-22m and a D_{AB} value of 24-28cm. By contrast, PEP 93 with a H_{AB} value of 23-24m has one of the highest D_{AB} values at 28-30 centimetres, and PEP

87 with highest H_{AB} values in this group 26-27m has only moderate D_{AB} values of 26-27cm. These findings prove that in sites of similar potential productivity of stands, estimated by H_{AB}, various stimulating and inhibiting conditions to tree diameter growth could be found. Gross yield that is produced in the stands could differ markedly, despite starting with the same stocking level.

4.1.3 Estimation of relation of potential site productivity and forest yield

The competitive conditions in each PEP were estimated by calculating competition index (CI_{Stand}) that describes exploitation of growing space in each stand. CI_{Stand} increased from 0.63 to 4.09 in the potentially high productive cluster ($H_{AB} \geq 26.5$ and $H_{AB} \leq 32.5$m) and from 0.93 to 3.39 in the potentially moderately productive cluster ($H_{AB} \leq 26.5$m, see Figure 4-4).

During a stand's formation period, CI_{Stand} value after stand's closure reaches its value of 1. Next, CI_{Stand} increases till reaching its maximum value, after which it decreases to, and even lower, than 1. Observation of most stands started in the phase when CI_{Stand} value was at its maximum and thus it's decline was recorded. However, PEPs 201 and 206 were investigated from very beginning and the values of CI_{Stand} were recorded throughout the inventory period, and changed from 1.17 to 1.63 at the age of 7-8 years to 3.52-3.73 at the age of 22-29 years.

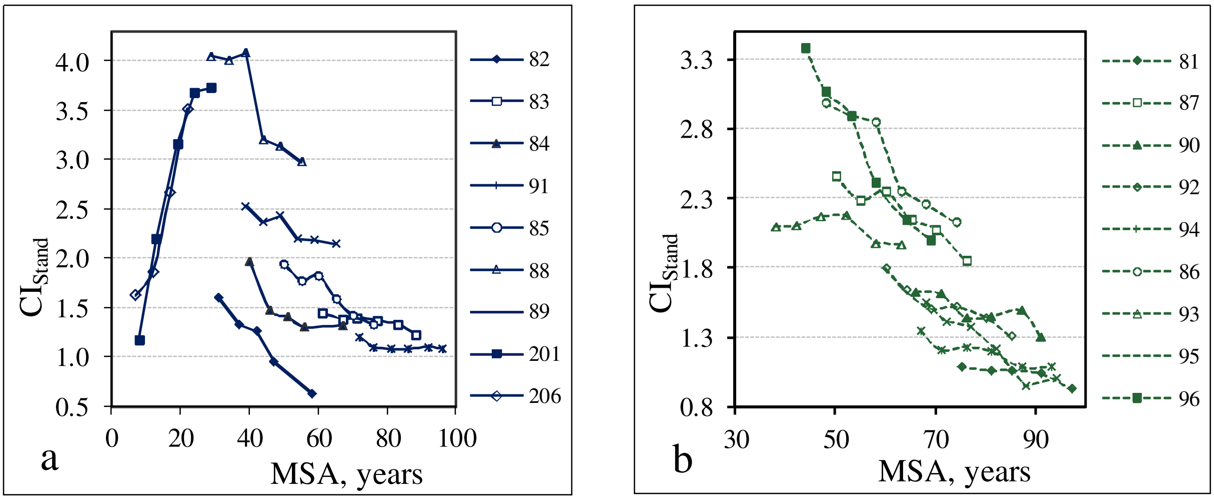


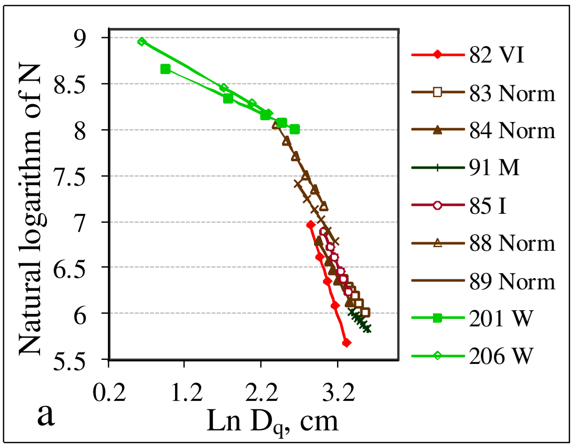
Figure 4-4: The dynamics of CI_{Stand} in potentially high productive cluster ($H_{AB} \geq 26.5$ and $H_{AB} \leq 32.5$ m; a) and potentially moderately productive cluster ($H_{AB} \leq 26.5$ m; b). MSA=mean stand age in years.

Very high CI_{Stand} values were also observed in PEP 88. This stand reached maximal CI_{Stand} value 4.01-4.09 at the age of 29 years and maintained this value for 10 years. Very high CI_{Stand} values at Y^{1-40}age are the result of a number of processes such as substantially decreased growing space for each tree, overcrowding of trees, very low self-thinning and decreased growing possibilities. Forest stands cannot maintain overcrowding for a long time, because it leads to the stand's stagnation or degradation. Proof of this lies in the data from

PEP 88 plot, such as the D_q and H_q ratio, commonly used in Lithuania rather than the H_q and D_q ratio, which for a growing stand is only 0.83-0.89 (Table 4-1). Additionally, the hundred largest trees diameter D_{100} and height H_{100} ratio decreases over time (1.29-1.18). By contrast, very low CI_{Stand} values were recorded in PEP 82 even though the MSA of this plot had not reached 60 years. This is not a result of competition for growing space, but rather disease and beetle outbreak or change of climatic conditions. The lower CI_{Stand} values in lower potential productivity cluster, where they have equal stand densities, are explained by lower potential possibilities of forest sites and more intense self-thinning at $Y^{1\text{-}40}$age (Figure 4-4b).

CI_{Stand} values are inversely proportional to D_{AB} values (Figure 4-3). This regularity is reflected in the results from PEPs 201 and 206. In these plots, CI_{Stand} increase with increasing age, but D_{AB} values decrease (Table 4-1). Accordingly, for PEP 82, the lowest CI_{stand} values (0.6-1.6) correspond with the highest D_{AB} values (39-42 cm). By contrast, for PEP 88, with highest CI_{Stand} values (3.05-4.03) appears the smallest D_{AB} values (30cm) in its group. The same tendencies are found in PEPs 86, 96, 81 and 94 that have H_{AB} values of 21-26m. The highest CI_{Stand} values (2.08-3.23) and the lowest D_{AB} values (21.5-26.0cm) are found in PEPs 86 and 96. However, in PEPs 81 and 91, CI_{Stand} values are lowest (0.99-1.28) but D_{AB} values are the highest (28.7-31.2, Table 4-1).

Stand density rule, introduced by REINEKE (1933) is used to describe the correlation between a stand's mean diameter and stem number per hectare. This study evaluated all 18 PEPs according to the same rule and estimated the coefficients b_N for Equation 3-31. The results are presented in Figure 4-5 and Table 4-1. According to b_N value, all PEPs were categorised into five groups of self-thinned stands: lightly (0 to -0.75), moderately (-0.76 to -1.25), normally (-1.26 to -1.75), heavily (-1.76 to -2.25), and very heavily (-2.26 and less).



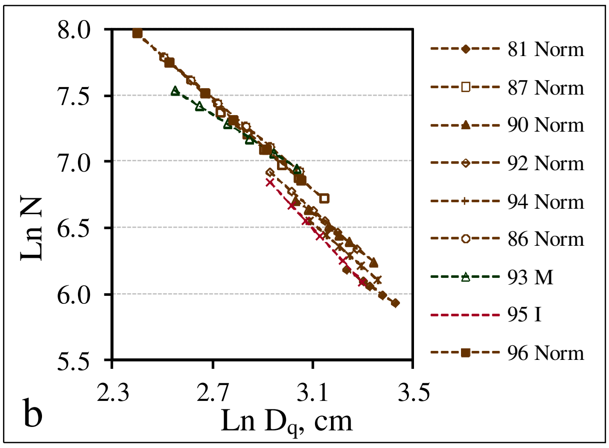


Figure 4-5: The relation between tree number and mean tree diameter in lightly (W), moderately (M), normally (Norm), heavily (I), and very heavily (VI) self-thinned forest stands, representing potentially high productive ($H_{AB} \geq 26.5$ and $H_{AB} \leq 32.5$ m; a) and potentially moderately productive clusters ($H_{AB} \leq 26.5$ m; b). Ln D_q=natural logarithm of D_q (quadratic mean diameter in cm).

Table 4-1: The main parameters, characterising productivity of forest sites and forest stands for pine tree species.

Plot No.	*H_{AB} group m*	*Age, years*		*H_{AB}*, m		*D_{AB}*, cm		*Stocking level*		*D_q/H_q*		*D_{100}/H_{100}*		*b_N*	*CI_{Stand}*		*V* $m^3\ ha^{-1}$	*GY* $m^3\ ha^{-1}$	*PAI_V* $m^3\ ha^{-1}$	*$PAI_{removed}$ %*
		First inv	Last inv	First inv	Last inv	First inv	Last inv	First inv	Last inv	First inv	Last inv	First inv	Last inv		First inv	Last inv	First inv	Last inv		
Forest stands of normal formation type																				
84	31	40	67	33,0	31,1	37,4	36,6	0,81	0,81	0,98	1,07	1,25	1,28	-1,62	1,72	1,31	345	440	8,6	44,0
83		61	88	30,6	31,3	36,1	36,7	0,90	0,96	1,07	1,14	1,33	1,35	-1,27	1,42	1,28	519	594	9,7	35,0
91		72	96	31,6	31,2	36,2	36,2	0,75	0,86	1,07	1,15	1,28	1,35	-0,93	1,15	1,10	486	537	7,5	31,0
Average																	450	524	8,6	37,1
88	28	29	55	29,2	29,9	30,0	30,3	1,16	1,24	0,83	0,89	1,29	1,18	-1,44	4,03	3,05	428	507	13,8	26,0
89		39	65	26,9	28,7	30,0	30,9	0,98	1,08	0,96	0,98	1,32	1,24	-1,29	2,45	2,16	410	478	11,8	25,0
85		50	76	28,7	29,0	33,0	33,1	0,94	0,86	1,02	1,07	1,32	1,32	-1,97	1,86	1,38	372	495	8,5	62,0
Average																	403	493	11,4	34,5
87	25	50	76	23,2	25,2	25,7	27,0	1,01	1,01	0,98	1,00	1,40	1,32	-1,58	2,37	1,96	359	422	8,6	37,0
92		60	85	23,0	24,5	27,0	28,6	0,91	0,89	1,07	1,12	1,44	1,42	-1,68	1,72	1,37	331	397	7,1	47,0
90		66	91	24,2	26,0	27,2	28,8	0,88	0,88	1,04	1,08	1,29	1,32	-1,50	1,62	1,40	373	440	8,0	42,0
94		67	93	22,8	24,1	28,7	29,6	0,83	0,81	1,18	1,21	1,47	1,44	-1,63	1,28	1,09	310	371	6,0	43,0
81		75	97	25,8	25,9	30,6	31,2	0,72	0,75	1,13	1,18	1,37	1,42	-1,31	1,07	0,99	326	368	5,4	48,0
Average																	340	400	7,0	42,7
93	22	38	63	21,1	23,2	27,4	28,0	0,98	1,09	1,12	1,10	1,50	1,39	-1,20	2,10	1,97	299	337	9,1	46,0
96		44	69	19,7	23,5	21,5	26,0	1,11	1,03	0,94	1,01	1,39	1,33	-1,70	3,23	2,08	309	398	10,5	37,0
86		48	74	19,7	23,0	21,7	24,9	1,10	1,09	0,97	1,01	1,43	1,36	-1,59	2,94	2,20	331	407	10,0	34,0
95		68	94	20,5	21,6	24,7	27,5	0,85	0,75	1,13	1,25	1,45	1,49	-2,04	1,48	0,97	247	326	5,6	58,0
Average																	297	367	8,7	35,1
Forest stands of accelerated formation type																				
82	31	31	58	32,6	30,5	41,5	39,6	0,76	0,52	1,08	1,16	1,37	1,34	-2,72	1,47	0,79	186	327	6,2	105,0
206	28	7	22	27,0	27,3	41,3	37,6	0,57	1,18	1,15	1,12	1,74	1,72	-0,47	1,75	3,10	115	117	10,0	2,0
201		8	29	25,7	30,7	40,3	37,7	0,67	1,44	1,20	1,00	1,92	1,49	-0,39	1,68	3,71	246	257	14,0	6,0
Average																	183	234	12,0	4,0

Where: H_{AB}=site productivity index according to the mean stand height at base age (100 years) in m; D_{AB}=site productivity index according to the stand mean diameter at base age in cm; D_q=quadratic mean diameter of remaining stand in cm; H_q=mean stand height of remaining stand in m; D_{100}=mean diameter of 100 largest trees per ha or stand top diameter in cm; H_{100}=mean height of 100 largest trees per ha or stand top height in m; CI_{Stand}=stand level competition index; b_N=the gradient of stand density rule proposed by Reineke; V=standing volume [$m^3\ ha^{-1}$]; GY=gross volume yield [$m^3\ ha^{-1}$]; PAI_V=periodic annual volume increment [$m^3\ ha^{-1}$]; inv=inventory; $V_{removed}$=volume of removed stand; $PAI_{removed}$=the percentage of self-thinned trees from periodic annual volume increment.

PEPs 201 and 206 comprise the first group due to very light initial self-thinning. At $Y^{1\text{-}40}$age these PEPs reached very high 1.24-1.46 stocking levels (Table 4-1, Figure 4-5). PEPs 91 and 93 comprise the second group due to moderate thinning. Even at the beginning of the research period, these $Prem^{81\text{-}100}$age or mature stands had reached higher than average stocking levels, which continued to increase later on. PEPs 81, 83, 84, 86, 87, 88, 89, 90, 92, 94 and 96 (the largest proportion of the PEPs) comprise the third group of normal thinning. These stands with very high initial stocking density have kept stable thinning intensity since the beginning of the study. PEPs 85 and 95 comprise the fourth group being of intensive thinning. These PEPs at the beginning of research (first inventory) had reached higher than average stocking levels. However, till the end of investigation (last inventory) it decreased by 0.1-0.15. Only one PEP 82 comprised the fifth, extremely heavily thinned group, of which the stocking level had, since the beginning of observation, decreased by more than 0.3. Forest stands that represents potentially high productive cluster are characterised by five self-thinning ranges. Accordingly, forest stands that represents potentially moderately productive cluster, natural intensity thinning is sufficiently dominant to be close to normal intensity.

Stocking level. The majority of PEPs were established on forest sites with initial stocking level 0.8-1.1. Other PEPs, 201 and 206, at 7-6 years old have reached 0.3-0.5 stocking level. PEP 81 being 75 years old had only 0.7 initial stocking level (Figure 4-6).

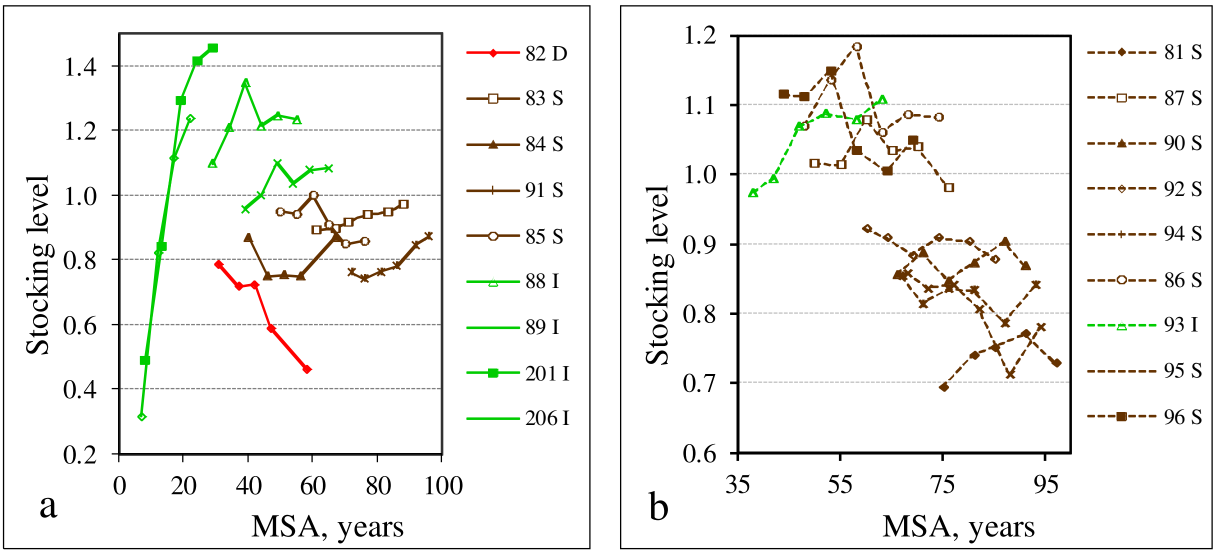


Figure 4-6: The dynamics of stocking level in stands with stable (S), increasing (I) and decreasing (D) stocking level, representing potentially high productive ($H_{AB} \geq 26.5$ and $H_{AB} \leq 32.5$ m; a) and potentially moderately productive clusters ($H_{AB} \leq 26.5$ m; b). MSA=mean stand age in years.

Forest stands could be categorised into three groups of stocking level dynamic: increasing, stable and declining (KULIEŠIS 1989a). For most stands, stocking levels have not changed more than ±0.1, these are stands of stable stocking level (PEPs 81, 83, 84, 85, 86, 87, 90, 91, 92, 94, 95 and 96). Stocking level changes by more than +0.1are recognised as increasing (PEPs 88, 89, 93, 201 and 206), whereas changes by more than -0.1 are declining (PEP 82). Stocking level increases by a factor of three in PEPs 201 (0.49 to 1.46) and 206 (0.32 to 1.24) maybe explained overcrowding of analysed stands due to light self-thinning.

Forest stands representing potentially high productive cluster have received stocking level values from 0.3 to 1.5. In these stands all three stocking level groups - increasing, stable and declining – are displayed in Figure 4-6a. Stocking levels in forest stands that represent potentially moderately productive cluster vary between 0.7 to 1.2, or in twice lower range (Figure 4-6b). Two varieties of stands, depending on types of forest formation, can be found on potentially productive sites: very productive stands with very high stocking levels and forest stands assigned to degradation. The variation of productivity in these stands is higher than in potentially moderately productive stands and can be quite low or reasonably high. The influence of forest formation type in potentially moderately or potentially lower productivity stands is lower than stocking level, thus the stocking level changes in lower scale.

Mean annual over bark stand diameter increment (i_D) in the PEPs varied from 0.21 to 0.39cm year^{-1}. According to the results, the values of i_D decrease then the values of mean diameter at base age D_{AB} decrease and the values of MSA increase (Figure 4-7). The analysed i_D from PEPs fits well to the model developed by KULIEŠIS (1993) with lower boundary of D_{AB}=22cm and with higher boundary of D_{AB}=40cm.

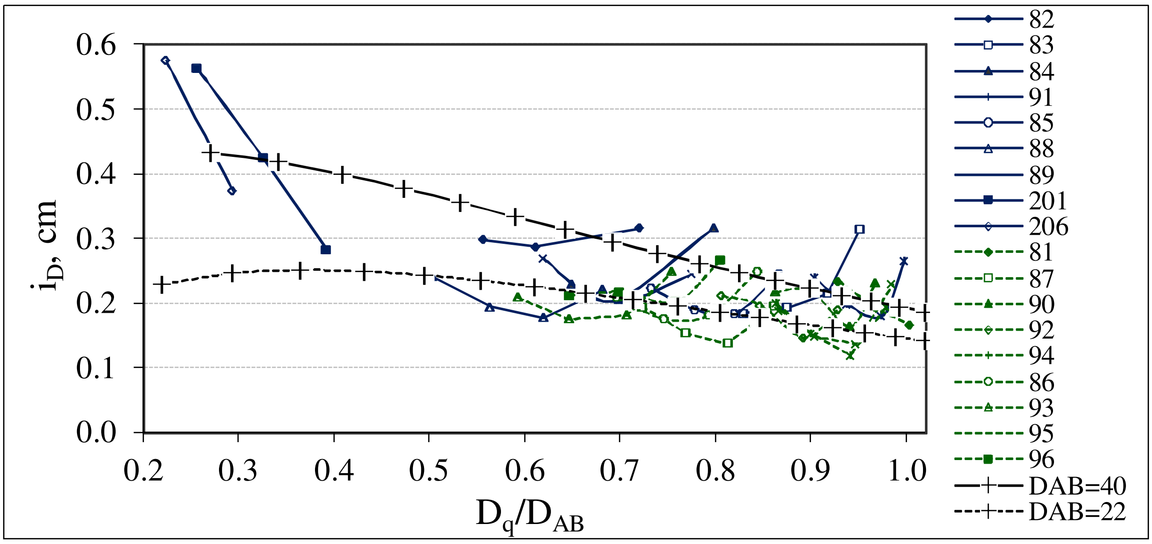


Figure 4-7: The dynamics of mean annual over bark stand diameter increment (i_D) in PEPs 81-96, 201 and 206. The range of 22-40m yield table's values (Kuliešis 1993) is shown by D_{AB} 22 and D_{AB} 40.

Only in three PEPs 88, 87 and 93, was i_D remarkably lower than estimated by the model (KULIEŠIS 1993). These differences appeared to be due to very high competition for growing space in these PEPs. CI_{Stand} values, at the beginning of the inventory period, were 4.05 in PEP 88 and 2.46 in PEO 87 (Table 4-1, Figure 4-4). According to KULIEŠIS (1993) model, CI_{Stand} values in these PEPs should have been 2.6 and 2.0 respectively.

The ratio of quadratic mean diameter D_q and mean stand height H_q in normal formation forest stands increases while MSA increases, increases while stand density decreases and CI_{Stand} for growing space values decreases (Table 4-1). In some exceptional cases, for example in very dense stands with very high CI_{Stand} values, D_q and H_q ratio can remain stable or even decrease with increasing age (PEP 93). The hundred largest trees' mean diameter D_{100} and mean height H_{100} ratio is usually higher than previous inventory by 0.2-0.5. This difference increases over time, as does site productivity estimated by H_{AB}. It should be noted that D_{100} and H_{100} ratio, comparing to D_q and H_q ratio, is more stable when MSA increases. D_{100} and H_{100} ratio increases with increasing mean age in normal formation type stands with CI_{Stand} not higher than 1.4-1.7 (see Table 4-1). Often, especially in less productive forest stands with high CI_{Stand} values (more than 1.7), a decrease of D_{100} and H_{100} ratio with increasing MSA is observed.

The categorisation of forest stands to one of the three formation types - slowed, normal and accelerated (KULIEŠIS 1989a), was according to the dynamics of stocking level, the gross yield and the percentage of periodic annual volume increment, accumulated for final harvest in each stand. From all 18 PEPs, 15 were classified as normal and 3 as accelerated forest formation types (Table 4-1). Forest stands with normal formation types are characterised by stable stocking levels that have not changed by more than ±0.1-0.2 since the beginning of inventory period. Only in PEPs 81, 84, 91, 94 and 95 had the stocking level increased by more than 0.1. The percentage of periodic annual volume increment, accumulated for final harvest in all 18 PEPs, varied from 56 to 75%, and only in PEPs 81, 85, 92, 93 and 95 was the proportion lower 38-54% (Table 4-1). The stocking level in these stands was lower than 1. Additionally, the intensity of self-thinning varied from normal to very heavy (b_N=-0.176-2.25). These stands could hardly be categorized as accelerated forest formation types due to the quite stable, sometimes increasing stocking level and quite high D_q and H_q ratio (1.1 and more). Three PEPs (201, 206 and 82) are classified as accelerated forest formation type due to very fast increase of stocking level between 7 and 29 years of age (PEPs 201 and 206) or decrease of the stocking level in between 31 and 58 years of age (PEP 82).

Due to very low self-thinning in PEPs 201 and 206 (b_N=-0.39 to -0.47), increasing CI_{Stand} and decreasing D_q and H_q ratio during the time, these stands have very high risk of moving into the stagnation phase. Moreover, the stand in PEP 82 had already started degrading. The slowed forest formation type is characterised by early very intensive thinning normally done by human intervention (KULIEŠIS 1989a). All PEPs were established in self-thinned, close to 1 stocking level stands. Thus, conditions such as increased growing space at $Y^{1\text{-}40}$age with steady increasing competition that usually characterises slowed forest formation type forests could not be found in the PEPs. Stands, classified to normal forest formation type, cover intervals of 29-97 years of age and stands classified to accelerated forest formation type cover intervals of 7-58 years of age. Furthermore, stands classified as normal forest formation type covers a wide range (H_{AB}=20-32m) of forest productivity sites that are common in Lithuanian pine forests. According to height dynamics, there are four forest groups, each having 3m intervals, and each group with four to five representative PEPs. Each H_{AB} group corresponds well with D_{AB} group. Normally, D_{AB} group is higher in absolute values by 2-6cm and only at $Y^{1\text{-}40}$age does the difference increase to 7-14cm.

Forest sites with H_{AB}=27-32m are characterised by stable height and diameter increment. The tree height growth on sites with H_{AB}=20-26m at 22-26 years of age has increased by 2-3 productivity metres. Accordingly, tree diameter growth has increased with quite similar intensity (D_{AB} 2-3cm).

It should be noted that while it would seem self-evident that increasing site productivity, estimated by H_{AB} or D_{AB}, would increase stand gross yield as well as the percentage of periodic annual volume increment accumulated for final harvest. However, this does not happen always. Only partial correspondence of stand gross yield and percentage of periodic annual volume increment accumulated for final harvest with H_{AB} or D_{AB} could be reported, even the starting stocking level of the PEPs was quite close or equal to 1 (Figure 4-8a,b).

The highest stand gross yield was observed not in the most productive sites, estimated by H_{AB}=30-32m, but on sites with H_{AB}=27-29m (PEPs 88 and 89) see, Table 4-1 and Figure 4-8a,b). Only one stand (PEP 95) with lowest H_{AB}=20-22m also had the lowest gross yield and accumulated volume increment part for final harvest. The lowest gross yields were recorded in PEPs 81, 90, 92 and 94. By contrast, the highest gross yields occurred in PEPs 86, 93 and 96 with H_{AB}=20-23m with PEPs 81, 90, 92 and 94 with H_{AB}=23-26m providing middle gross yields.

To conclude, stand gross yield is affected not so much by potential growth conditions, estimated by site index H_{AB}, but rather by available growing space for each tree, thinning intensity and its timing, and forest formation type. CI_{Stand} is one of the best variables that characterise self-thinning conditions and their adequacy to formation of normal forests in the best way. The value of CI_{Stand} shows if the forest is over dense (CI_{Stand} >1) or over thinned (CI_{Stand} <1) compared to normal forest (no surplus or lack of trees, KULIEŠIS et al. 2010). The value of CI_{Stand} in stands of 30-40 years of age varies from 1.5 to 4.0. The highest CI_{Stand} values have been found in stands with H_{AB}=27-29m and H_{AB}=21-23m. CI_{Stand} have remained higher in these stands compared to stands with H_{AB}=30-32m or H_{AB}=24-26m throughout the inventory period. There is a rule that the highest CI_{Stand} values inversely correspond with D_{AB} values, which means that while CI_{Stand} values increase, both annual volume increment values and D_{AB} values decrease (Table 4-1, Figure 4-8a,b).

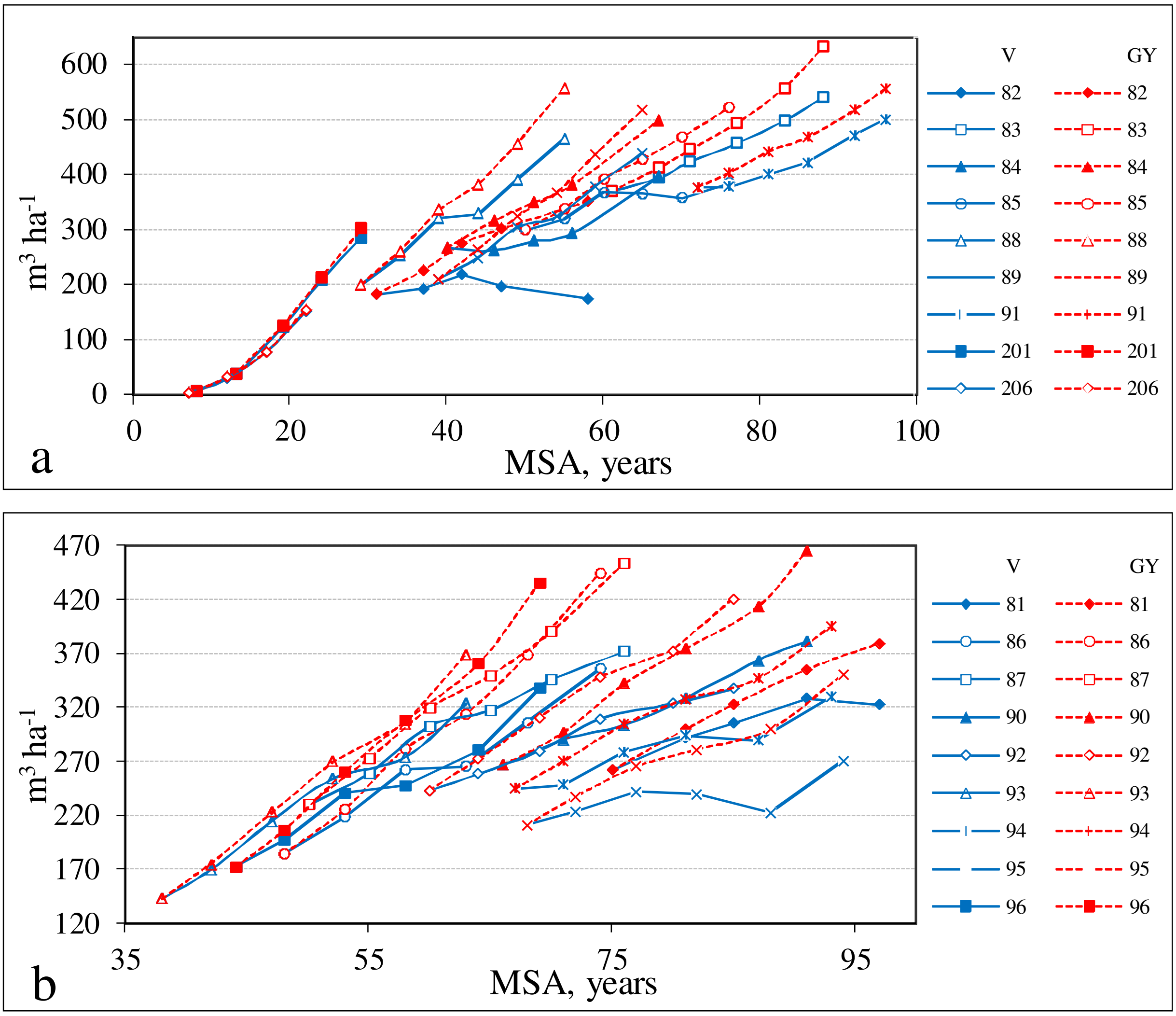


Figure 4-8: The dynamics of accumulated standing volume (V) and gross yield (GY) growing in potentially highly productive sites ($H_{AB} \geq$ 26.5 and $H_{AB} \leq$32.5 m; a) and potentially moderately productive sites ($H_{AB} \leq$26.5 m; b). MSA=mean stand age in years.

The intensity of self-thinning is characterised by the volume share of self-thinned trees compared to the total volume in the stand. In the PEPs the intensity of self-thinning varied from 34.5 to 42.7%. Indeed, forest stands least effected by self-thinning grow on sites with H_{AB}=27-29m and H_{AB}=21-23m (Table 4-1).

This means that higher productivity, gross yield and share of volume accumulated for final harvest do not occur simply due to faster growth of trees on the most potentially productive sites, but have been achieved through less intensive self-thinning. It is important to mention that the higher initial density on sites with H_{AB}=21-23m and H_{AB}=27-29m, compared with stands that grow on sites with H_{AB}=24-26m and H_{AB}=30-32 m, determined the lower D_q and H_q ratio in the first group's stands. Accordingly, higher initial density decreased their resistance to spontaneous self-thinning, caused by unfavourable climatic conditions like wind and wet snow. Correlation analysis of stand level variables (gross yield (GY), mean stand age (MSA), stocking level (SL), Site productivity indices according to the mean stand height and quadratic mean diameter (H_{AB} and D_{AB}) and stand level competition index (CI_{stand}) revealed valuable results (Table 4-2).

Table 4-2: The correlation between main indices of forest stands, sites and gross yield.

	GY	***MSA***	***SL***	***H_{AB}***	***D_{AB}***	***CI_{stand}***
GY	1	0,722**	0,058	0,373**	-0,019	-0,306**
MSA		1	-0,260**	-0,122	-0,328**	-0,616**
SL			1	-0,150	-0,353**	0,846**
H_{AB}				1	0,834**	-0,125
D_{AB}					1	-0,252*
CI_{stand}						1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

The study found highly significant gross yield (significance level 0.01) correlations between MSA, H_{AB} and CI_{Stand}. Stand stocking level reliably (significance level 0.01) correlates with MSA, D_{AB} and CI_{Stand}. With increasing age, in all PEPs stocking level, D_{AB} and especially CI_{Stand} had decreasing tendencies. H_{AB} site index had the highest correlations with D_{AB}. With increasing stocking level, CI_{Stand} increases, but site index D_{AB} decreases. Results of correlation analysis in some PEPs had other tendencies than described. Thus, it is required to take into account growth and natural mortality that appear in each stand.

To summarise all results, it is possible to state that formulated hypothesis "Site quality is the most important factor that affects forest growth and yield" is only partially confirmed. Site productivity defines the growth potential that could be reached in certain sites. However, the possibility to reach this potential strongly depends on forest formation type. Because of this, stands growing on more fertile sites could be less productive than stands growing on less fertile sites. Thus, the competitive situation for growing space in each stand during rotation period has to be carefully controlled.

4.2 The relationship between competition and tree parameters

4.2.1 Description of tree height-diameter curves

Since tree heights were measured only for sample trees, heights for the rest of the trees had to be modelled. For this purpose, the study used the MICHAILOFF (1943) formula that is included in the BWINPro-S simulator. While modelling tree height (h) from diameter at breast height (d_{bh}), two important issues have to be checked: (i) statistical goodness of fit of MICHAILOFF (1943) model to analysed data and (ii) plausibility of height curves, produced by the various inventories.

Statistical analysis. The statistical goodness of fit of the MICHAILOFF (1943) model was evaluated by visual goodness of fit and by coefficient of determination. The visualisation of MICHAILOFF (1943) model, is presented only for two PEPs 85 and 94, and only for the first and last inventories (Figure 4-9). Yet, Coefficients of determination, were estimated for each PEP and inventory and are listed in Appendix 3b.

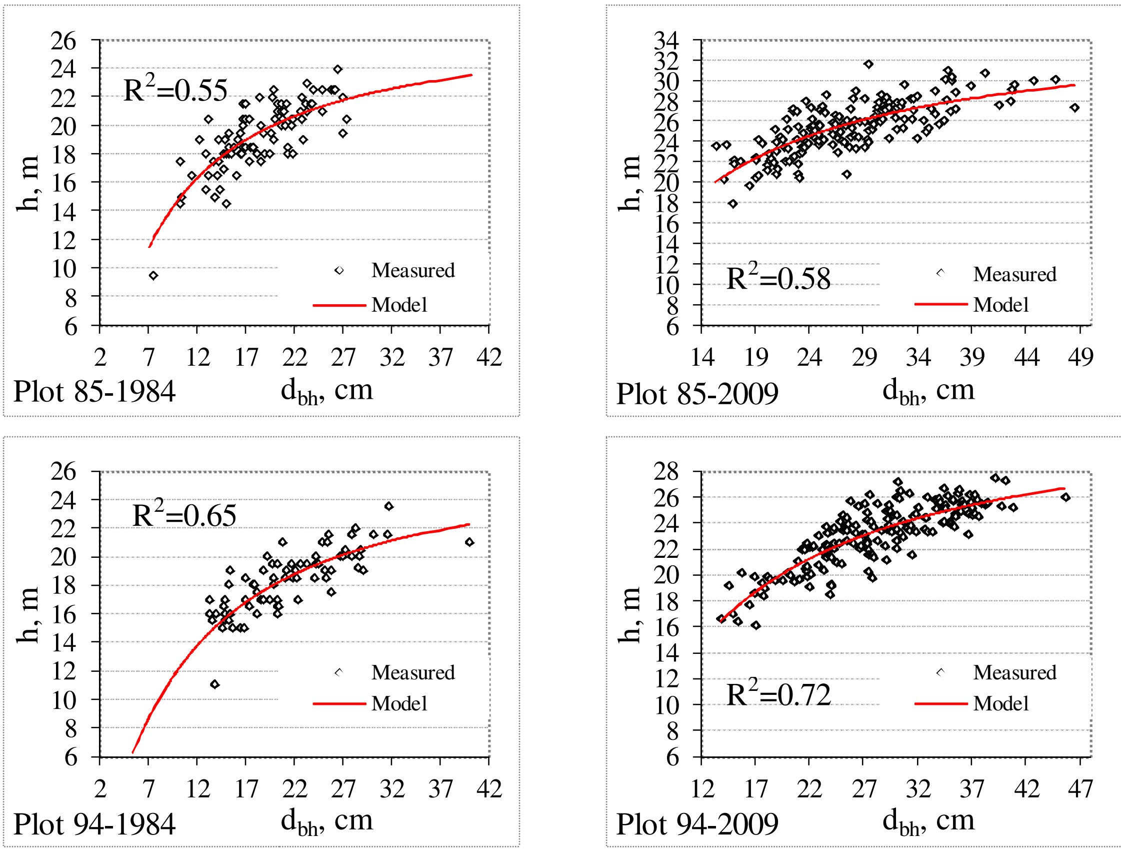


Figure 4-9: The dependence of tree height from tree diameter at breast height (d_{bh}), based on MICHAILOFF (1943) model, for PEPs 85 and 94, for the first (1984) and the last (2009) inventories.

Figure 4-9 shows that d_{bh} and h relations are clearly not linear. Thus, the nonlinear shape of MICHAILOFF (1943) formula fits very well to analysed data for both PEPs and analysed inventories. Furthermore, this asymptotic model does not cut the abscissa (X) axis. Because of this, with increasing d_{bh} modelled tree heights only increase. The MICHAILOFF (1943) model's curves in the first inventory are much steeper compared to the last inventory (Figure 4-9). In the last inventory, the curve appears to be flatter and shifted to the right side according to abscissa (X) axis and up according to the ordinate (Y) axis. These curves precisely follow the growth patterns of trees.

The coefficient of determination (R^2) in PEP 85 in the first inventory was 0.55 and in the last inventory 0.58. Accordingly, R^2 in PEP 94 in the first inventory was 0.65 and in the last inventory 0.72. So R^2 in both PEPs remained high and increased with increasing MSA.

The coefficients of determination of the MICHAILOFF (1943) model in the other PEPs and inventories can be found in Appendix 3, b). The maximum coefficient of determination value - 0.88 - was recorded in PEP 201 in the 1994 inventory. By contrast, the minimum R^2 value 0.46 was estimated in PEP 91 for the 2009 inventory. Lower than 0.5 R^2 values were estimated only in PEP 91 for the inventories in 1988, 1994 and 2009. The highest share (71%) of R^2 values ranged from 0.6 to 0.8. However, 11% of PEPs had R^2 values higher than 0.8 and 16% had R^2 values less than 0.6 but more than 0.5.

Plausibility of height curves, produced by various inventories is the second important issue while analysing height curves. Plausible curves mean that height curves produced by all inventories steadily shift to the right side of abscissa (X) axis and the upper side of the ordinate (Y) axis and do not intersect each other. Figure 4-10 visualises the dynamics of height curves during the inventories for PEPs 85 and 91.

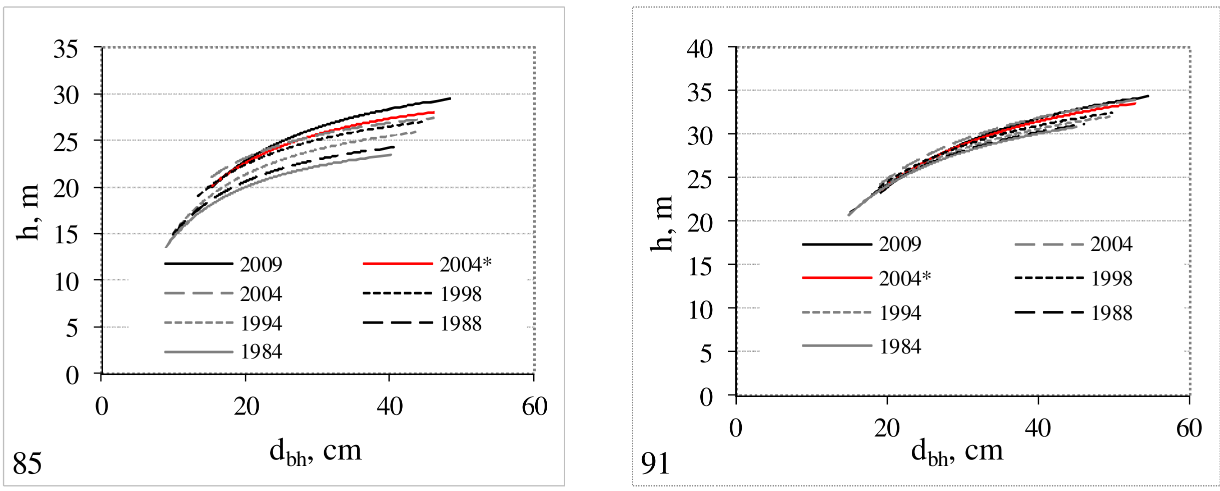


Figure 4-10: The dynamics of height curves during inventories for PEPs 85 and 91. Red color (*marked) indicates smoothed curves.

Figures that describe the dynamics of height curves for the other PEPs can be found in Appendix 3, a). Height curves only in PEPs 85 and 91 (2004 inventory) were not plausible because they intersected the 2009 height curves. Thus, they needed to be smoothed. The resulting smoothed height curves of PEPs 85 and 91 (2004 inventory) had a slightly steeper slope and did not intersect the 2009 year inventory curve.

These results of statistical analysis indicate a reliable statistical fit of the MICHAILOFF (1943) model to the analysed data.

4.2.2 Description of tree height to crown base curves

Modelling height to crown base (h_{cb}) in older stands. As the values of h_{cb} were measured only for sample trees, h_{cb} values for the rest of trees were modelled. Tree height (h) and tree crown length (cl) correlations were the most suitable variables for this purpose. The models developed were evaluated according to statistical parameters. The plausibility of cl curves produced by various inventories was also taken into account.

Statistical parameters. The following statistical parameters were checked by this study: 1) visual goodness of fit, 2) statistical significance of regression models and 3) coefficients of determination. The visual goodness of fit to clarify h and tree cl relations is presented only for two PEPs 85 and 94 and for the first and last inventories (Figure 4-11).

Figure 4-11 shows that measured tree cl and h relations are clearly linear. The modelled curves shift to the right side of the abscissa (X) axis and down according to ordinate (Y) axis. Additionally, the slope of the curves becomes smaller. The coefficient of determination (R^2) in PEP 85 in the first inventory was 0. 44 and in the last 0.47. Accordingly, R^2 in PEP 94 in first inventory was 0.53 and in the last 0.6.

All analysed regression models were highly significant (Appendix 4b), with significance values being not higher than 3.9×10^{-5} (much lower than required 0.05 significance level).

The maximum coefficient of determination (R^2) value 0.82 was recorded in PEP 93 in the 1988 inventory and the minimum value 0.26 was estimated in PEP 85 in the 2004 inventory. The highest proportion (56%) of R^2 values ranges from 0.6 to 0.8 7% had R^2 value higher than 0.8, and 27% had R^2 value less than 0.6 but more than 0.5. Only 10% of all cases had R^2 values lower than 0.5.

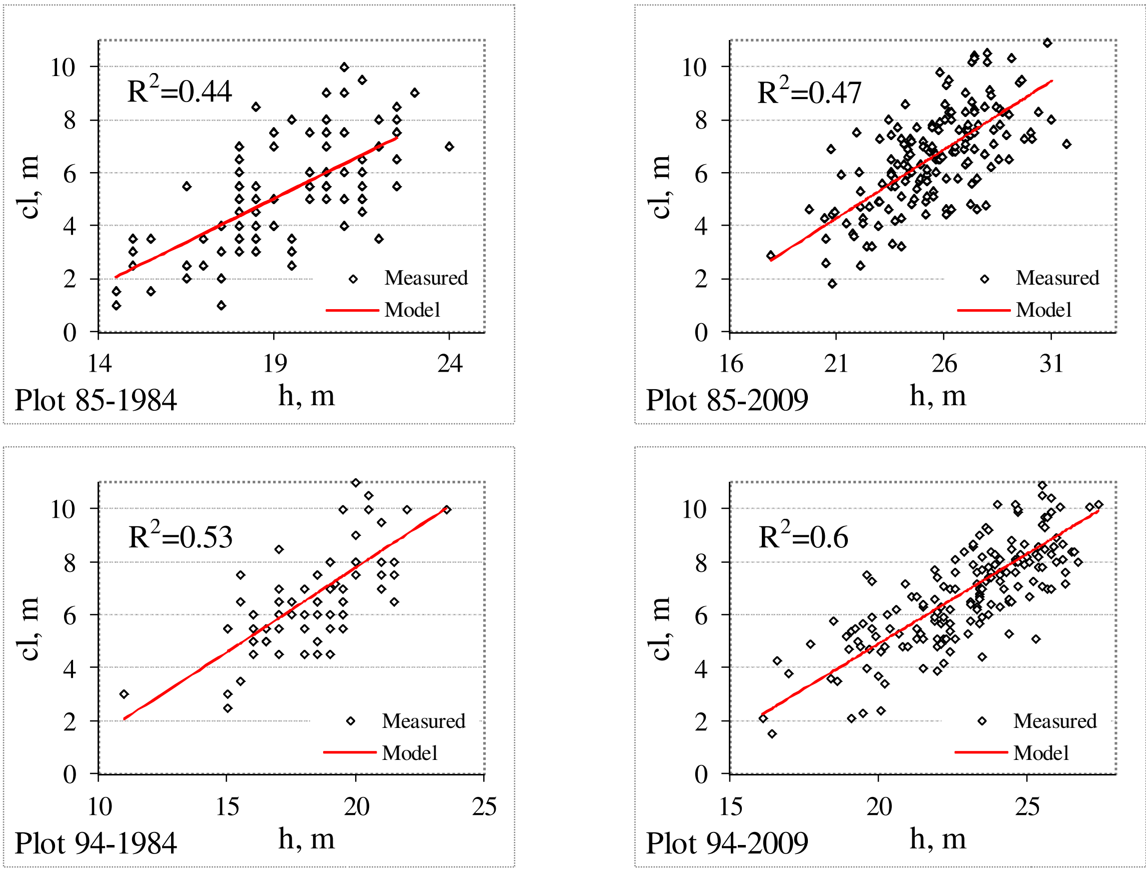


Figure 4-11: Visualisation of tree crown length (cl) from tree height (h) curves for the first (1984) and the last (2009) inventories for PEPs 85 and 94.

Plausibility of cl curves. Figure 4-12, visualises the dynamics of cl curves over all inventories for PEPs 85 and 94. Theoretically, cl curves with increasing age should shift to the right of the abscissa (X) axis and downward the ordinate (Y) axis with a decreasing slope of the curve. Curves should not intersect each other. However, some of curves did not follow this pattern, for example the curves of the 1988, 1994 and 1998 inventories do intersect each other. Curves intersecting between inventories were also recorded in PEPs 81, 86, 87, 88, 90, 91, 92, 93, 94, 95 and 96 (Appendix 4a).

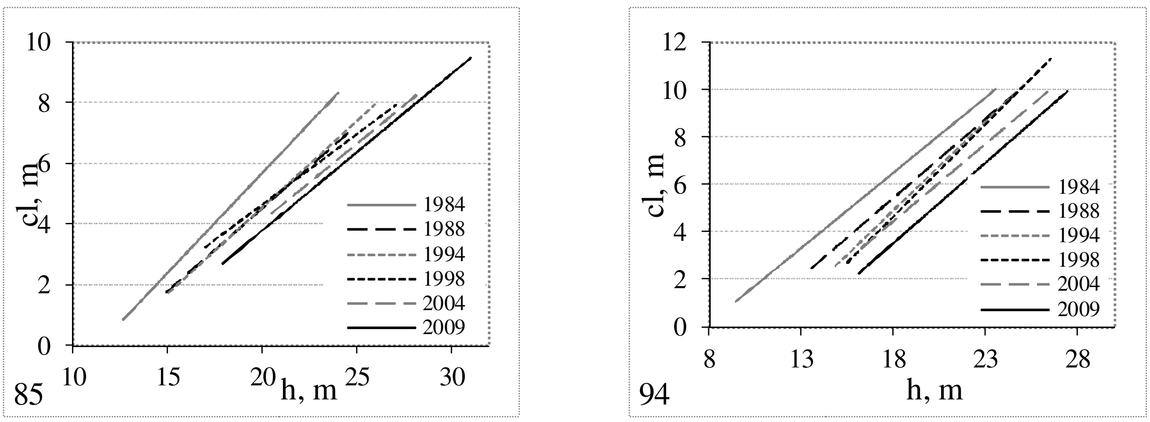


Figure 4-12: The dynamics of crown length (cl) curves during all inventories for PEPs 85 and 94.

Results of statistical analysis indicate reliable statistical fit of crown length models to the analysed data. Yet, in 13 PEPs, the curves from various inventories intersect each other.

Modelling h_{cb} in young stands. The estimation of h_{cb} in PEPs 201 and 206, is based on relative crown length ($cl_{relative}$) and logarithmic tree height linear relations (Equation 4-1).

$$cl_{relative} = -0.2031 \cdot \ln(h) + 1.0308 \quad (4\text{-}1)$$

Where: $cl_{relative}$=relative crown length; h=tree height in m; ln=natural logarithm.

The results of statistical analysis are presented in Table 4-3. The coefficient of determination R^2 for presented model was 0.55. Also, the selected model is highly significant (3.33×10^{-54}). Thus, both model coefficients also are highly significant with low standard error values.

Table 4-3: Statistical parameters of relative crown length ($cl_{relative}$) model.

R^2	Significance	Coefficient values		Standard Error of Coefficient		Significance of Coefficient	
		a_0	a_1	a_0	a_1	a_0	a_1
0.5542	3.33E-54	1.0308	-0.2031	0.0326	0.0106	2.70E-97	3.33E-54

Figure 4-13 describes visual model's fit to the data, in which the relation of $cl_{relative}$ and tree height (h) is not linear. Trees that are shorter than 10 metres have higher $cl_{relative}$ values, up to 95%, however trees taller than 10 metres have $cl_{relative}$ values that can only reach up to 60%.

Figure 4-14 presents Q-Q plot for the model's residuals. Estimated rank-based z-scores for model residuals are clearly located on the red linear trend line with R^2 value equal to 0.994. Rank-based z-score values only for the smallest (-0.2) and for the largest (0.2) residual values negatively and positively deviate from red linear trend line.

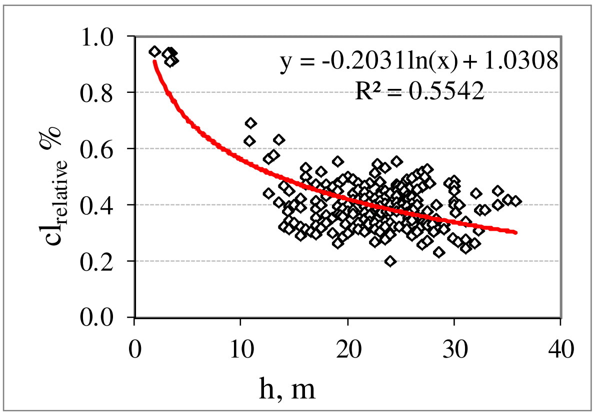


Figure 4-13: Relative crown length ($cl_{relative}$) model.

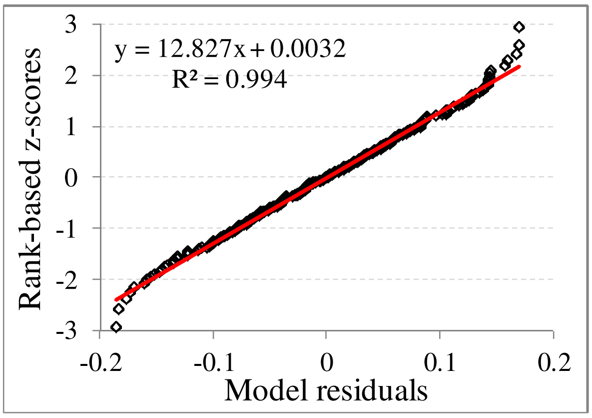


Figure 4-14: Q-Q plot for relative crown length ($cl_{relative}$) model.

To summarise, the results clearly describe clarified $cl_{relative}$ and tree height nonlinear relations. The estimated rank-based z-score values indicate normal distribution of model residuals, and the R^2 for shows good model fit to the data; and finally the model and model's coefficients were highly significant. Thus, this $cl_{relative}$ model is accepted.

4.2.3 Developing tree crown width curves

Crown widths (cw) were measured only in the last inventory and only for sample trees. Consequently, the cw measurements for all the PEPs' non-sample trees in the last inventory had to be estimated, and a multiple regression model of tree cw for the previous inventories needed to be created.

Modelling cw in last inventory. To model cw in last inventory in each PEP, a simple linear regression model between tree cw and d_{bh} was used. Figure 4-15 visualises these correlations for PEPs 85 and 94, and shows quite clearly that they are linear. The cw models for the other PEPs are listed in Appendix 5a).

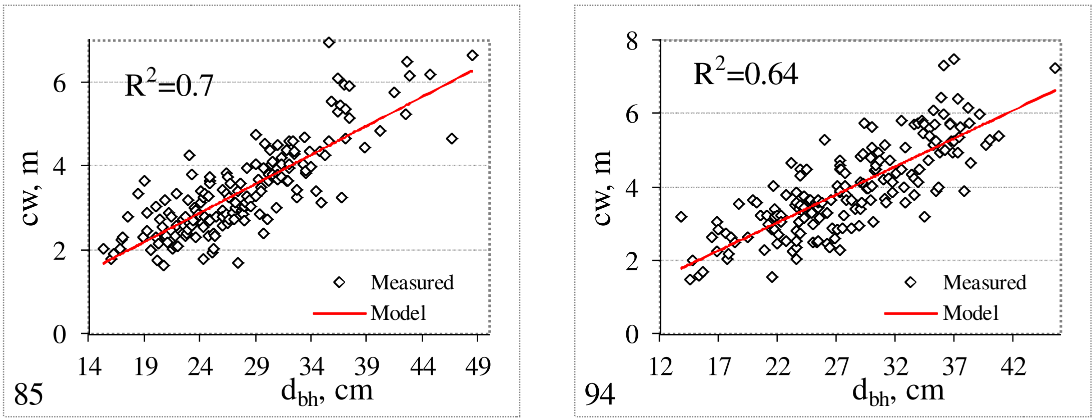


Figure 4-15: Crown width (cw) models for permanent PEPs 85 and 94 in the last (2009) inventory.

The statistical analysis of the simple regression models was based on: coefficients of determination (R^2), the model's significance, standard errors and significance of each coefficient in the model (Appendix 5b). The maximum R^2 value of 0.77 was observed in PEP 96 and the minimum value 0.49 was recorded in PEP 91. Only in PEPs 83, 91 and 95 was the R^2 value lower than 0.6 but equal to, or higher than, 0.49. All regression models were highly significant. Also all coefficients a_1 were highly significant. The lowest significance level was $1.8x10^{-9}$ and the highest $5.5x10^{-56}$.

Statistical analysis of simple linear regression models indicates the models' goodness of fit to the analysed data. Thus, linear models are accepted.

Modelling cw for previous inventories. To develop a multiple linear cw regression model, five independent variables were used: tree diameter at breast height (d_{bh}), tree height (h), crown length (cl) tree height to crown base (h_{cb}) and mean stand age (MSA). To define the predictive capacity of each independent variable, a correlation matrix was developed (see Table 4-4). High inter-correlation of independent variables show that some of them are multicollinear.

Crown width (cw) had the highest and lowest Pearson correlation values with, respectively, d_{bh} (+0.82) and h_{cb} (-0.38). Multicollinearity was recorded between h and tree h_{cb} (correlation value 0.92), thus h_{cb} was excluded from further analysis.

Table 4-4: Correlation matrix for multiple linear crown width regression model.

	cw	**d_{bh}**	**h**	**cl**	**h_{cb}**	**MSA**
cw	1	0.82	0.57	0.66	0.38	0.44
d_{bh}		1.00	0.85	0.74	0.69	0.78
h			1.00	0.65	0.92	0.67
cl				1.00	0.31	0.32
h_{cb}					1.00	0.67
MSA						1.00

All correlations were highly significant, (less than 0.001), at the 0.01 level (2-tailed).

Where: cw=crown width in m; d_{bh}=diameter at breast height in cm; h=tree height in m; cl=crown length in m; h_{cb}=height to crown base in m; MSA=mean standard age in years.

In the next step, a multiple linear cw regression model was constructed using the independent variables d_{bh}, h, cl and MSA. Figure 4-16 describes the linear relations between these independent and the dependent variables.

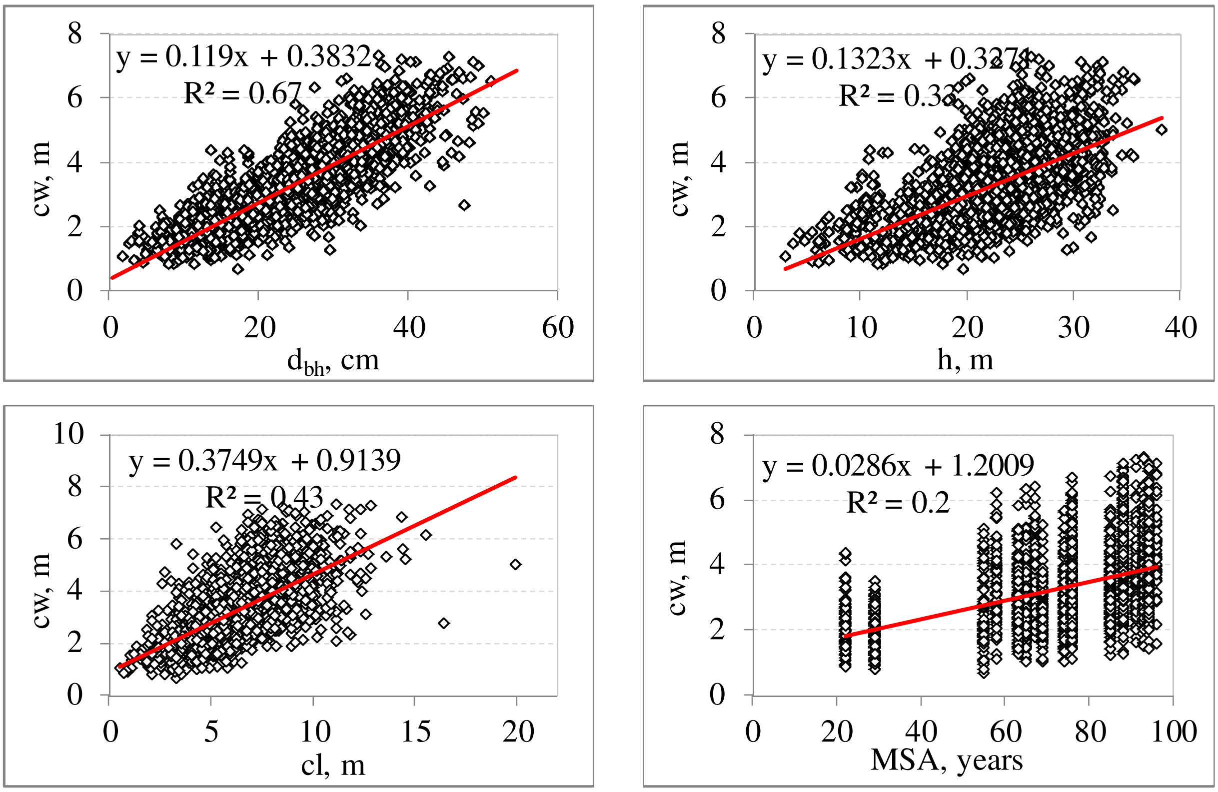


Figure 4-16: Graphical visualisation of relations between crown width (cw) and tree diameter at breast height (d_{bh}), tree height (h), crown length (cl) and mean stand age (MSA).

All the analysed independent variables were put into a multiple regression model, and the model was tested by statistical analysis (Table 4-5). The model's coefficient of determination was 0.74. The model was highly significant with a significance level equal to 0. Accordingly, all the model's coefficients were highly significant. The significance levels of model's coefficients ranged from $1.3x10^{-7}$ to 0. Partial correlation showed that d_{bh} had the highest predictive capacity of all independent variables (0.69). Collinearity diagnostics revealed the threshold coefficients a_1 and a_2. VIF values for a_1 and a_2 were 4.93 and 4.31 respectively.

Table 4-5: Statistical parameters of multiple linear crown width regression model.

R^2	Sign	Coefficients				Correlation		VIF
		Coef	Value	Std Err	Sign	Zero order	Partial	
0.74	0	a_0	1.1035	0.064	4.8E-63			
		a_1	0.1578	0.003	0.0E+00	0.82	0.69	4.93
		a_2	-0.1177	0.005	1.9E-108	0.58	-0.44	4.31
		a_3	0.0945	0.009	1.2E-23	0.66	0.21	2.39
		a_4	0.0050	0.001	1.3E-07	0.45	0.11	1.96

Where: R^2=coefficient of determination; Sign=significance value; Coef=coefficients; Std Err=standard error; VIF=variance inflation factor.

In the next step, regression assumptions were checked by plotting Q-Q and evaluating homogeneity of variance of the model's residuals. The distribution of rank-based z-scores for the model's residuals in the Q-Q plot indicated normal distribution (Figure 4-17). For very small residual values rank-based z-scores deviated positively from the trend line. For very high residual values it negatively deviated from the trend line. However, trend line's coefficient of determination R^2 remained very high 0.992.

Homogeneity of variance of the model's residuals was checked by plotting the model's residuals against the cw modelled values (Figure 4-18). The constructed model, according to Loess regression, works precisely in the range from start growth to 4.5 metres, but in ranges from 4.5 to 5.5 metres, the model tends to overestimate up to 0.075 metres. Finally, for cw values higher than 5.5 metres it tends to underestimate cw values up to 0.4 metres.

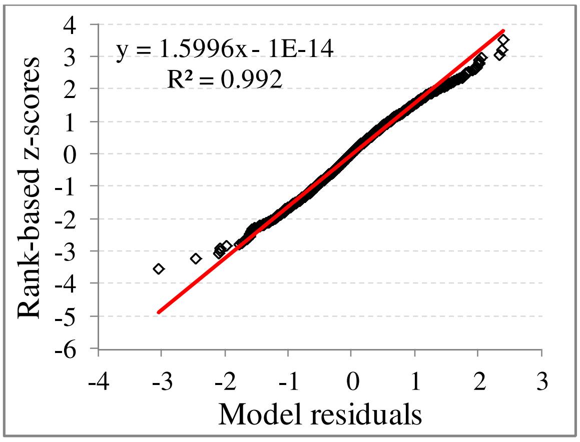


Figure 4-17: Normal Q-Q plot of crown width model's residuals.

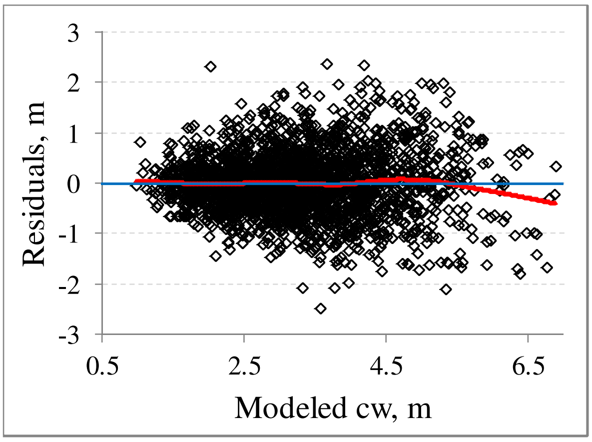


Figure 4-18: Distribution of residuals against modelled crown width (cw) values.

To summarise, multiple linear cw regression model was constructed by using d_{bh}, h, cl and MSA as independent variables. Statistical analysis of the constructed cw multiple linear regression model shows reliable model's fit to analysed data. Thus, this model is accepted.

4.3 Analysis of competition for growing space

The capability of 20 CIs to model periodic mean annual tree basal area (i_{ba}) and height (i_h) increment was evaluated by this study. The basis for evaluation was partial correlation analysis, implemented for each PEP and inventory. Results for all PEPs are presented in Appendix 6a, b, c, d, e, f, g, h).

4.3.1 Clarifying the principles of partial correlation analysis

Figure 4-19 shows, as an example, the results from PEP 88 at the 1994 inventory and CI_4 combined with the HCB 80 selection method. In Figure 4-19a the simple linear regression shows that CI_4 explained 57% of the i_{ba} variation (R^2=0.57).

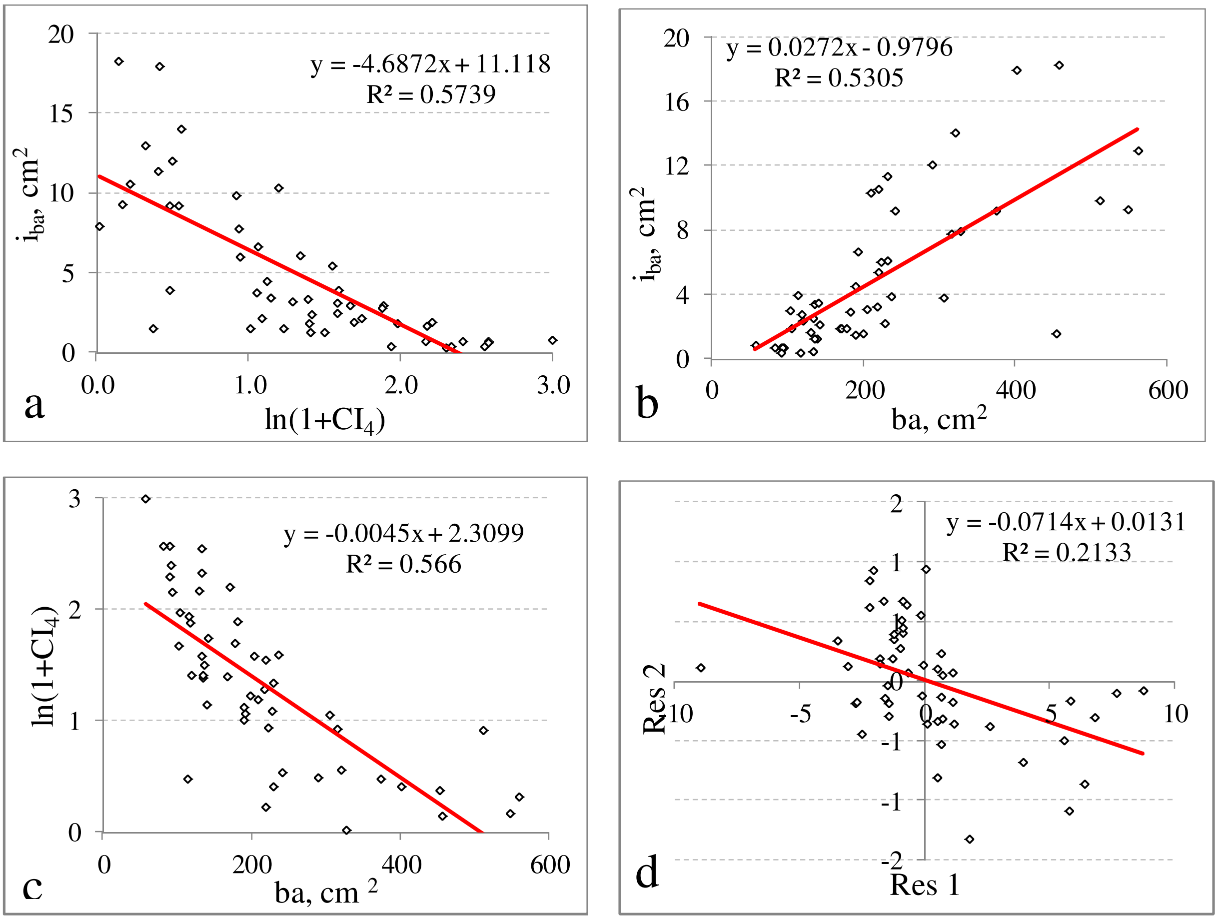


Figure 4-19: Partial correlation analysis in permanent experimental plot 88, 1994 inventory, CI_4 combined with HCB 80 selection method. Linear regression: (**a**) periodic mean annual basal area increment (i_{ba}) and logarithmic CI_4. (**b**) i_{ba} and basal area (ba). (**c**.) logarithmic CI_4 and ba. (**d**) residuals observed from (b, Res_1) and (c, Res_2) linear regressions.

However, as shown in Figure 4-19b, the control variable basal area (ba) explained 53% of i_{ba} variation (R^2=0.53). Figure 4-19c shows a strong relationship between CI_4 and basal area (R^2=0.57). Thus, as shown in Figure 4-19d, CI_4 explained the additional 21% of the variation in i_{ba} that is not explained by the basal area of the tree. Plotting the residuals obtained from the i_{ba} and ba regression (Res_1) against the residuals of the CI_4 and ba regression results in a value of R^2=0.21 (Res_2). CI_4 could explain 21% of i_{ba} variation from (100-53%=47%) 47% of variation that is not explained by ba. So, adding CI_4 to i_{ba} and ba regression would increase explained part of variation to 63% (53%+(47%*0.21)=63%). In the same way multiple linear regression of i_{ba} against ba and CI_4 would give R^2=0.63.

4.3.2 The partial impact of competition to basal area and height increment

Partial impact of competition on periodic mean annual basal area (i_{ba}) increment: Table 4-6 shows the ranking of all selection methods with all CIs according to their statistical influence on i_{ba}. Our analysis showed that the selection method HCB 80 combined with CI_4 was the most effective for i_{ba} modelling. This combination scored the highest mean partial correlation coefficient of -0.168 and the largest share of significant cases (39.08%). Index CI_5 combined with selection method HCB 80 was ranked second. The mean partial correlation coefficient for this combination was -0.161 and the proportion of significant cases was 34.48%. Index CI_6 combined with selection method HCB 80 was ranked third. Its mean partial correlation coefficient was lower than previous combinations (-0.152), but the share of significant cases remained high at 34.48%.

Table 4-6: Ranking of competition indices according to their effect on periodic mean annual basal area increment. Summarised mean results from all permanent experimental plots and inventories.

i_{ba}=f(ba) mean R^2	Ranking CI	Selection method	Competition index	Partial correlation	
				Mean Pearson Coefficient (r)	Share of significant cases %
0.521	1	HCB 80	CI_4	-0.168	39.08
	2	HCB 80	CI_5	-0.161	34.48
	3	HCB 80	CI_6	-0.152	34.48
	4	HCB 80	CI_7	-0.151	29.89
	5	SB 60	CI_6	-0.147	33.33
	6	HWCW 60	CI_6	-0.145	25.29
	7	HWCW 60	CI_7	-0.137	26.44
	8	HWCW 60	CI_8	-0.136	28.74
	9	SB 60	CI_5	-0.135	29.89
	10	SB 60	CI_7	-0.134	32.18
	11	HCB 80	CI_8	-0.132	28.74
	12	HCB 80	CI_3	-0.129	24.14
	13	HWCW 60	CI_3	-0.128	26.44
	14	SB 60	CI_4	-0.114	28.74
	15	HWCW 60	CI_4	-0.113	16.09
	16	SB 60	CI_3	-0.102	19.54
	17	HWCW 60	CI_5	-0.089	10.34
	18	SB 60	CI_8	-0.073	21.84
	19	Distance independent	CI_2	-0.063	14.94
	20	Distance independent	CI_1	0.067	8.05

Index CI_8 combined with selection method SB 60 showed the poorest performance of the distance dependent indices. Its mean partial correlation coefficient was only -0.073 and the share of significant cases was 21.84%. The distance independent indices C_2 and C_1 had low impacts on i_{ba} and were ranked lowest with mean partial correlation results of -0.063 and 0.067 respectively and a proportion of significant cases of 14.94% and 8.05%, respectively.

In summary, the partial influence of 18 distance dependent and 2 distance independent CIs on the periodic mean annual basal area increment was assessed. The distance dependent index CI_4 combined with the selection method HCB 80 had the highest mean partial correlation value and highest mean share of significant cases. Distance independent CIs showed the smallest mean partial capacity to predict the mean annual basal area increment, however the difference in the mean partial correlation coefficient between the best distance dependent CI and the best distance independent CI was only 0.105. No CI performed significantly better than any of the others. The hypothesis “Distance dependent competition indices had higher partial correlation with tree basal area increment than distance independent competition indices” formulated at the beginning was confirmed by these results.

Partial impact of competition on periodic mean annual height (i_h) increment: Table 4-7 shows the ranking of all of the selection methods associated with all of the CIs, according to their influence on i_h.

Table 4-7: Ranking of competition indices according to their effect on periodic mean annual height increment. Summarised mean results from all permanent experimental plots and inventories.

i_h=f(h) mean R^2	Ranking CI	Selection method	Competition index	Partial correlation	
				Mean Pearson Coefficient (r)	Share of significant cases %
0.118	1	Distance independent	CI_2	-0.264	27.59
	2	SB 60	CI_4	-0.221	20.69
	3	SB 60	CI_5	-0.211	20.69
	4	SB 60	CI_3	-0.209	24.14
	5	SB 60	CI_6	-0.194	20.69
	6	HCB 80	CI_7	-0.190	14.94
	7	SB 60	CI_7	-0.187	18.39
	8	HCB 80	CI_6	-0.186	18.39
	9	HCB 80	CI_5	-0.159	14.94
	10	HCB 80	CI_3	-0.148	9.20
	11	Distance independent	CI_1	-0.148	18.39
	12	HCB 80	CI_4	-0.142	11.49
	13	HWCW 60	CI_6	-0.137	12.64
	14	HWCW 60	CI_7	-0.129	12.64
	15	HWCW 60	CI_4	-0.125	8.05
	16	HWCW 60	CI_5	-0.116	6.90
	17	HWCW 60	CI_3	-0.114	8.05
	18	HWCW 60	CI_8	-0.026	4.60
	19	HCB 80	CI_8	0.016	0.00
	20	SB 60	CI_8	0.052	1.15

In contrast to all expectations, the distance independent index CI_2 showed the highest mean partial correlation coefficient of -0.264 and the highest share of significant cases of 27.59%. The other distance independent index CI_1 was ranked 11th, with a mean partial correlation coefficient of -0.148 and a share of significant cases of 18.39%. The best distance dependent index was ranked 2nd and was CI_4 combined with selection method SB 60, with a mean partial correlation coefficient of -0.221 and a share of significant cases of 20.69%. Its mean partial correlation coefficient was lower than the respective value of the distance independent index CI_2 by 0.043. The distance dependent index CI_5 combined with selection method SB 60 was ranked 3rd, with a mean partial correlation coefficient of -0.211 and a share of significant cases of 20.69%. The least influential CI of all, ranked 20th, was the distance dependent index CI_8 combined with selection method SB 60, its partial correlation coefficient was 0.0528 and its share of significant cases was 1.15 %.

Thus, the results showed that the formulated hypothesis "Distance dependent competition indices had higher partial correlation with tree height increment than distance independent competition indices" is incorrect and, thus, had to be rejected.

4.3.3 The impact of competition on mean diameter and height increment

Figure 4-20 shows the influence of competition on relative values of periodic mean annual diameter ($i_{\bar{d}}$) and periodic mean annual height ($i_{\bar{h}}$) increment. Figure 4-20a shows that as CI_4 values increase, relative $i_{\bar{d}}$ values decrease.

Figure 4-20b shows a different influence of competition on the relative $i_{\bar{h}}$. The relative values reach a local maximum when competition is slightly higher than zero. After this maximum, the relative $i_{\bar{h}}$ steadily decreases with increasing CI_4 values.

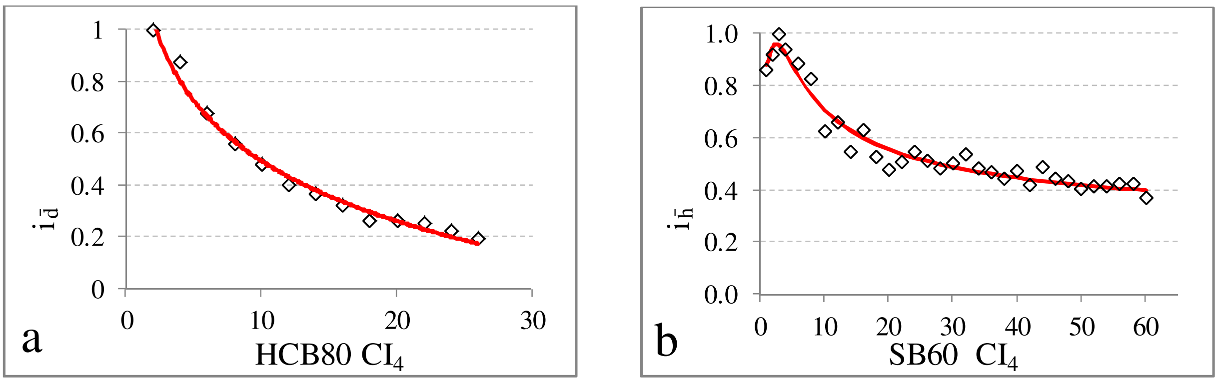


Figure 4-20: Influence of competition on relative values of periodic mean annual (a) diameter ($i_{\bar{d}}$) and (b) height ($i_{\bar{h}}$) increment.

In summary, competition has a consistent negative impact on tree diameter growth; with increasing competition the diameter increment decreases. By contrast to this, a small amount of competition stimulates tree height growth, but stronger competition also has a negative impact on tree growth.

4.4 Modelling tree growth

Modelling growth of pine trees mainly concerns three issues: 1) modelling tree diameter increment, 2) modelling tree height increment and 3) modelling exclusion of trees due to natural mortality. Additionally, a comparison of Lithuanian and Saxonian yield tables was aimed at revealing differences in growth conditions. For this section, the following hypothesis was formulated "A re-parameterised model based on Lithuanian data fits better under Lithuanian conditions (regarding diameter, basal area, height increment and mortality)".

4.4.1 Comparison of Lithuanian and Saxonian yield tables

The comparison of Lithuanian (KULIEŠIS 1993) and Saxonian (LEMBCKE et al. 2000) yield tables was done to reveal if growth conditions of pine trees in Lithuania differs from growth conditions in Saxony. If so, growth models used in Saxony have to be re-parameterised under Lithuanian growth conditions.

Dynamics of mean stand height. Figure 4-21 visualises the main differences between mean stand height (H_q) over mean stand age (MSA). The 10 curves in this figure cover the range of H_{AB} from 16 to 34m with increment steps of 2m.

The Lithuanian H_q curves up to the 100 years appeared higher than in German curves. The difference was more remarkable between curves that represent sites H_{AB} of 16-18m. With increasing MSA, at the age of about 100 years, these curves coincide and intersect.

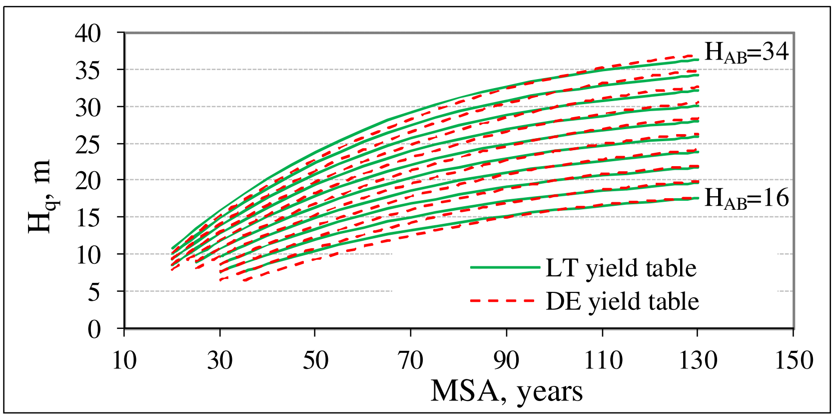


Figure 4-21: Comparison of Lithuanian (LT) and Saxonian (DE) yield tables by evaluating the dynamics of mean stand height (H_q) over the mean stand age (MSA).

Dynamics of quadratic mean diameter. Much more remarkable differences were found while comparing the dynamics of D_q over the MSA (Figure 4-22). The curves in this figure cover the same range of H_{AB} from 16 to 34m with increment steps of 2m. The Lithuanian curves up to 70 years appeared a little higher than the German curves. However, after 70 years, the German D_q curves were much steeper than the Lithuanian D_q curves.

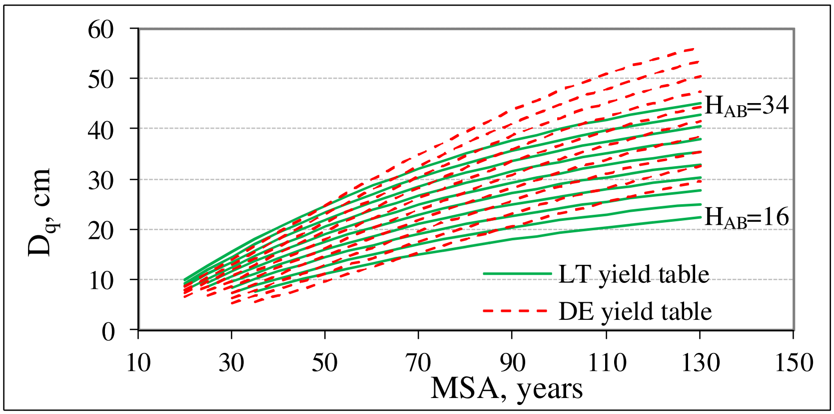


Figure 4-22: Comparison of Lithuanian (LT) and Saxonian (DE) yield tables by evaluating the dynamics of quadratic mean diameter (D_q) over the mean stand age (MSA).

The dynamics of quadratic mean diameter increment. The differences of diameter growth of trees could be better illustrated by analysing dynamics of annual quadratic mean diameter increment (ZD_q) over the D_q and D_{AB} ratio. According to Figure 4-23 in Lithuania's yield table, in very low $Y^{1\text{-}40}$age values (D_q and D_{AB} ratio=0.16) ZD_q reaches the highest values 0.35cm per year. By contrast, in $Mat^{101\text{-}140}$age (D_q and D_{AB} ratio=1) ZD_q values remain very low, and are equal to 0.157cm per year.

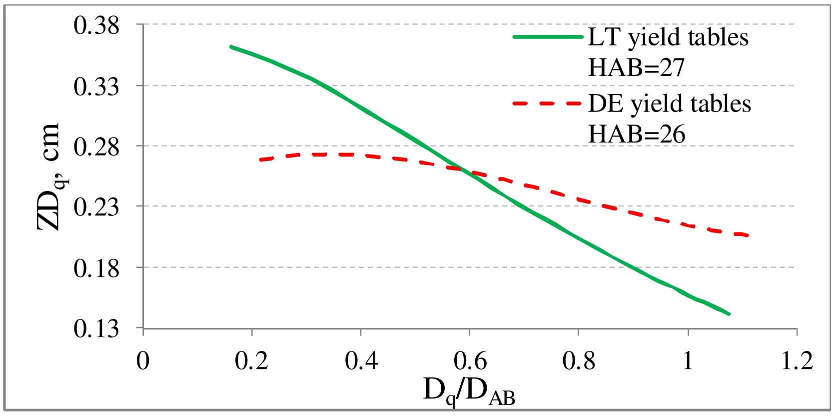


Figure 4-23: Comparison of Lithuanian (LT) and Saxonian (DE) yield tables by evaluating the dynamics of quadratic mean diameter increment (ZD_q) over quadratic mean diameter (D_q) and quadratic mean diameter at base age (D_{AB}) ratio.

Data recorded in Saxony's yield table, show that the culmination of ZD_q values comes later than in Lithuania (D_q and D_{AB} ratio=0.32) and is equal to 0.274cm per year. Yet, in $Mat^{101\text{-}140}$age (D_q and D_{AB} ratio=1) ZD_q values remains comparably high 0.22cm per year.

The dynamics of the growing trees ha^{-1}. Figure 4-24 presents the dynamics of N over MSA. Three different curves for each yield table show the dynamics of N on the various site types (H_{AB}=18m, 24m and 30m). The lowest density is found in stands growing on the most productive sites and vice versa. As displayed in Figure 4-24, up to 70 years, pine trees in Saxony grow much more densely than in Lithuania. But then the curves intersect from 70 years on and pine trees in Lithuania grow more densely than in Germany.

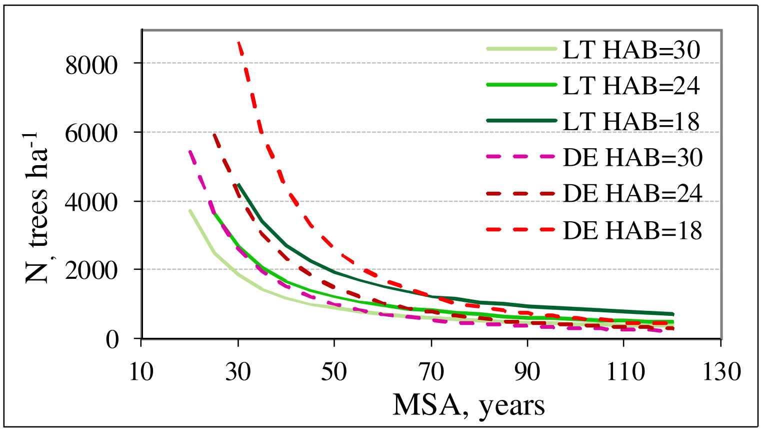


Figure 4-24: Comparison of Lithuanian (LT) and Saxonian (DE) yield tables by evaluating the number of growing trees ha^{-1} (N) over mean stand age (MSA).

The yield levels of pine trees. Figure 4-25 visualises the dynamics of standing volume (V) over the mean stand height (H_q) recorded in Lithuanian (KULIEŠIS 1993) and Saxonian (LEMBCKE et al. 2000) yield tables. Curves cover site index ranges of H_{AB} from 24 to 30m with stocking level equal to 1. It can be noted that up to the H_q values of 25m, V is higher in Saxony stands. However, from this point onwards, Lithuanian curves become steeper than Saxony curves, meaning that Lithuania's produced volumes are higher. The differences between Lithuanian and Saxony yield levels are less than 30 m^3 ha^{-1}, equivalent to 10%.

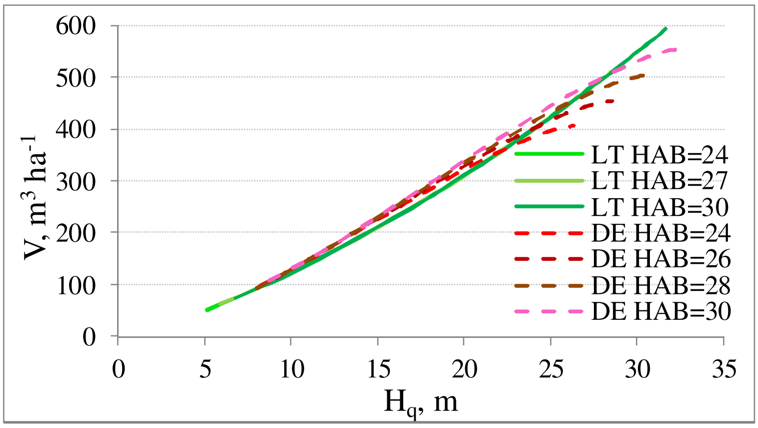


Figure 4-25: Comparison of Lithuanian (LT) and Saxonian (DE) yield levels recorded in yield tables by plotting standing volumes (V) against mean stand heights (H_q) for different site productivity indices (H_{AB}) with stocking level equal to one.

Growth differences of mean stand height over the mean stand age in Lithuania and in Saxony are minor. However, remarkable growth differences of diameter of pines over the mean stand age are notable. Comparison of the yield levels of pine produced in Lithuania and Saxony, did not show remarkable distinctions. According to German yield tables, the growth of pines at Y^{1-40}age is slower, but trees retain the growth energy and release it in the later growth stages. The growth of Lithuanian pines is also faster at Y^{1-40}age, however they do not manage to maintain the same growth energy in the later growth stages. Thus, the growth models of Saxony have to be re-parameterised for Lithuanian growth conditions.

4.4.2 Developing new tree diameter increment model

The periodic mean five year diameter increment (i_{d5}) model was developed to predict tree diameter growth (Equation 4-2). It is a nonlinear model with independent variables d_{bh}, D_q, D_{AB} and a distance dependent CI_4 with selection method HCB80.

$$i_{d5} = 0.0131 \cdot \left(\left(\frac{D_q}{D_{AB}} \right)^{-0.4512} \right) \cdot \left(\frac{d_{bh}}{D_q} \right)^{1.4051 \cdot \left(\left(D_q \right)^{-0.2954} \right)} \cdot \left(\left(CI_4 + 1 \right)^{-0.2999} \right) \quad (4\text{-}2)$$

Where: i_{d5}=periodic mean five year diameter at breast height increment in m; d_{bh}=tree diameter at breast height in cm; D_q=quadratic mean diameter in cm; D_{AB}=quadratic mean diameter at a base age in cm; CI_4=distance dependent competition index with selection method HCB80 (Table 3-3, No. 4).

The model's goodness of fit was estimated by the coefficient of determination (R^2). Multicollinearity of independent variables was estimated by using correlation of the matrix of the model's coefficients. Regression assumptions were checked by setting the Q-Q plots and by testing homogeneity of variance of model's residuals.

Coefficient of determination R^2 value 0.483 indicated model's goodness of fit to the analysed data (Table 4-8). While evaluating multicollinearity, the coefficient a_0 had the highest correlation with coefficient a_4 (-0.74); coefficient a_1 had the highest correlation with coefficient a_2 (0.46); coefficient a_2 had the highest correlation with coefficient a_3 (-0.95) and coefficient a_4 had the highest correlation with coefficient a_1 (0.35). According to these results, multicollinearity was recorded only between coefficients a_2 and a_3 (-0.95<-0.8).

Table 4-8: Parameter estimates of developed periodic mean five year tree diameter increment model.

R^2	**Coefficients**			**Correlation**				
	Coef	**Value**	**Std Err**	a_0	a_1	a_2	a_3	a_4
0.483	a_0	0.0131	0.0002	1	0.25	0.27	-0.43	-0.74
	a_1	-0.4512	0.0075	0.25	1	0.46	-0.34	0.35
	a_2	1.4051	0.1438	0.27	0.46	1	-0.95	-0.01
	a_3	-0.2954	0.0478	-0.43	-0.34	-0.95	1	0.2
	a_4	-0.2999	0.01	-0.74	0.35	-0.01	0.2	1

Where: R^2=coefficient of determination; Coef=coefficients; Std Err=standard error.

Figure 4-26 visualises the Q-Q plots of the i_{d5} model's residuals. According to Figure 4-26, rank-based z-scores for residual values lower than -1.5 and higher than 1.5 have a negative deviation from the trend line, and it shows little skewedness to the left. However, the coefficient of determination of the z-scores trend line remained very high 0.98. Thus, the distribution of the model's residuals was close or equal to normal.

Figure 4-27 visualises the homogeneity of variance of the model's residuals. The red Loess nonparametric regression line clearly shows if model's residuals are equally distributed in all range of i_{d5} values. Thus the model tends: up to 1cm of the modelled i_{d5} value to underestimate by -0.1cm; in the interval of 1-1.3cm to overestimate by 0.04 cm; in the 1.3-2cm interval to underestimate up to -0.03 cm; in the next interval of 2-3.7cm to overestimate by 0.1cm; and finally in the last segment up to 5cm to underestimate i_{d5} values up to -0.35cm.

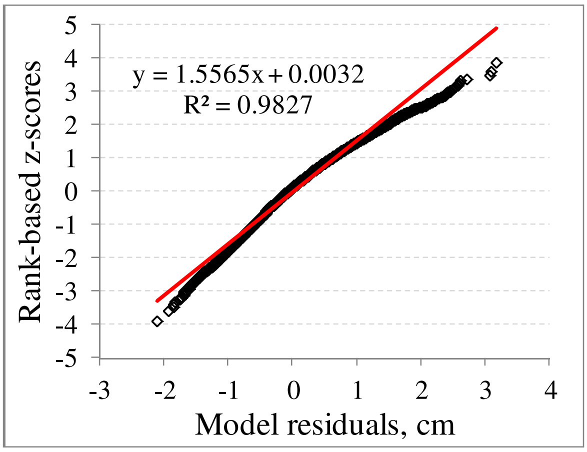


Figure 4-26: Q-Q plots of periodic mean five year diameter increment (i_{d_5}) model residuals.

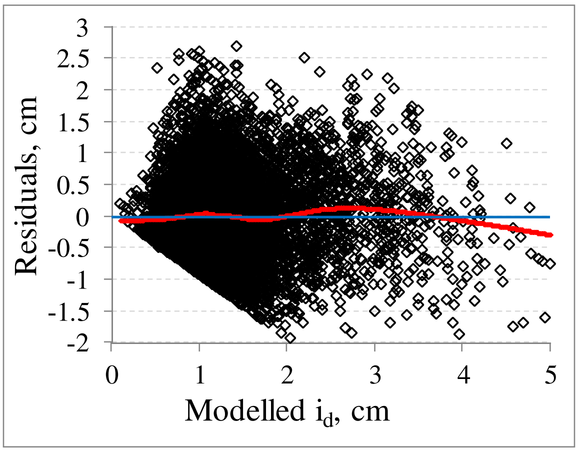


Figure 4-27: Homogeneity of variance of periodic mean five year diameter increment (i_{d_5}) model residuals.

To conclude, the i_{d5} nonlinear model was developed using the independent variables d_{bh}, D_q, D_{AB} and distance dependent CI_4 with selection method HCB80. According to statistical analysis, the model's coefficient of determination indicated model's goodness of fit to the analysed data. Multicollinearity was recorded, but only between coefficients a_2 and a_3. While checking regression assumptions, the distribution of the model's residuals was close or equal to normal. Analysis of homogeneity of variance of the model's residuals and Loess nonparametric regression did not show any systematic tendency, only some minor fluctuations of Loess nonparametric regression line around abscissa (X axis) were recorded.

4.4.3 Modelling basal area increment of trees

The twin aims of conducting multiple regression analysis was to (a) evaluate the periodic mean five year basal area increment model (i_{ba_5}) used in BWINPro-S (SCHRÖDER et al. 2007) on Lithuanian PEPs and (b) to reveal possible deviations of this model when it is applied in Lithuania. Furthermore, all regression parameters used in the SCHRÖDER et al. (2007)[2] i_{ba_5} model were estimated from PEPs located in Lithuania, so the model was re-parameterised under Lithuanian growth conditions and evaluated by applying the same statistical analysis.

4.4.3.1 Evaluation of basal area increment model Developed for Saxony

The *SCHRÖDER*^{7OR} i_{ba_5} additionally involves height to crown base (h_{cb}) and crown width (cw) models (see Table 3-5). Thus, to evaluate *SCHRÖDER*^{7OR} i_{ba_5} it is required to check h_{cb}, cw and logarithmic i_{ba_5} models on Lithuanian PEPs.

The *SCHRÖDER*$^{7OR}h_{cb}$. The model's statistical evaluation was done by estimating the coefficient of determination (R^2), checking multicollinearity between the model's coefficients and validating if regression assumptions are satisfied.

The R^2 for this model remained very high and was equal to 0.882. Coefficient a_0 had the highest correlation with coefficient a_3 (-0.79); coefficient a_1 had the highest correlation with coefficient a_2 (0.87); coefficient a_2 had the highest correlation with coefficient a_1 (0.87). Also, coefficient a_3 had the highest correlation with coefficient a_2 (-0.86). High inter-correlation values show possible multicollinearity between coefficients a_1 and a_2, a_2 and a_3 (Table 4-9).

Table 4-9: Statistical parameters of *SCHRÖDER*$^{7OR}h_{cb}$ (height to crown base) model, tested on Lithuanian PEPs.

R^2	Coefficients			Correlation				
	Coef	Value	Std Err		a_0	a_1	a_2	a_3
0.882	a_0	1.7838	0.088	a_0	1	0.14	0.40	-0.79
	a_1	-0.1943	0.057	a_1	0.14	1	0.87	-0.71
	a_2	0.0174	0.002	a_2	0.40	0.87	1	-0.86
	a_3	-1.0552	0.044	a_3	-0.79	-0.71	-0.86	1

Where: R^2=coefficient of determination; Coef=coefficients; Std Err=standard error.
Source: SCHRÖDER et al. (2007).

Figure 4-28 visualises Q-Q plots for the analysed model. According to this figure, rank-based z-scores for residual values lower than -3 and higher than 3 have a positive deviation from the red trend line. However, coefficient of determination of z-scores trend line remained very high 0.99. Thus, the distribution of model's residuals was close or equal to normal.

[2] Henceforth abbreviations will refer to the original SCHRÖDER et al. (2007) models (*SCHRÖDER*^{7OR}) and the re-parameterised (*SCHRÖDER*^{7ReP}). These abbreviations will prefix the model type e.g. *SCHRÖDER*$^{7OR}h_{cb}$, *SCHRÖDER*$^{7ReP}i_{ba5}$.

Figure 4-29 visualises the homogeneity of variance of model's residuals. The red Loess nonparametric regression line clearly shows that until h_{cb} modelled value 12m, the model tends to overestimate up to 0.4m. However, in the interval from 12 to 27m, the model has a very clear tendency to underestimate h_{cb} values up to -1.1m.

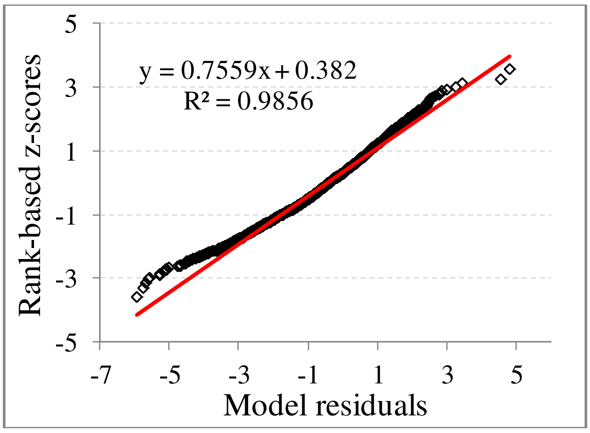


Figure 4-28: Q-Q plots of SCHRÖDER[7OR] height to crown base (h_{cb}) model residuals.

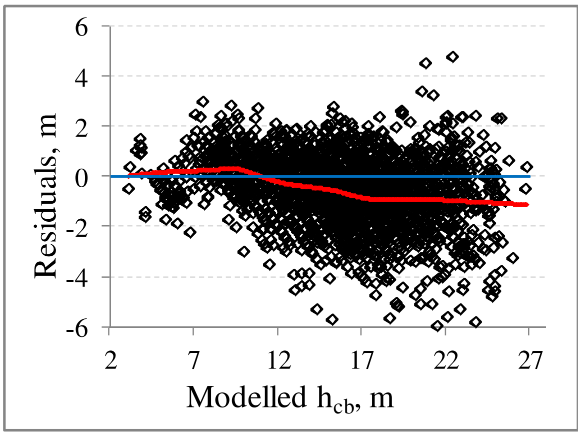


Figure 4-29: Homogeneity of the variance of *SCHRÖDER*[7OR] height to crown base (h_{cb}) model residuals.

To summarise, the high coefficient of determination showed that the *SCHRÖDER*[7OR]h_{cb} has very good capacities to predict h_{cb} of Lithuanian pine trees. Analysis of Q-Q plots showed normal or close to normal distribution of the model's residuals. However, the model had a very clear tendency to underestimate h_{cb} values higher than 12m. Thus, this model had to be re-parameterised for Lithuanian growth conditions.

The *SCHRÖDER*[7OR]*cw*. This nonlinear model was evaluated using the same analysis as the h_{cb} model. The results of the statistical analysis are presented in Table 4-10. The R^2 for this model remained comparably high and was equal to 0.528. Coefficient a_0 had the highest correlation with coefficient a_2 (-0.999), coefficient a_1 had the highest correlation with coefficient a_2 (-1.000), coefficient a_3 had the highest correlation with coefficient a_1 (-0.978), and coefficients a_4 and a_5 had the highest inter-correlation (-0.955). According to the results, coefficients a_1, a_2 and a_3 as well as coefficients a_4 and a_5 were multicollinear.

Table 4-10: Statistical parameters of *SCHRÖDER*[7OR]*cw* (crown width) model, tested on Lithuanian PEPs.

R^2	Coefficients			Correlation					
	Coef	Value	Std Err	a_0	a_1	a_2	a_3	a_4	a_5
0.528	a_0	3.1516	55.358	1	-1.000	0.999	0.977	-0.022	0.084
	a_1	0.0828	0.505	-1.000	1	-1.000	-0.978	0.041	-0.103
	a_2	18.5202	372.867	0.999	-1.000	1	0.973	-0.051	0.115
	a_3	0.8416	0.614	0.977	-0.978	0.973	1	0.043	-0.011
	a_4	0	0.01	-0.022	0.041	-0.051	0.043	1	-0.955
	a_5	0	0.274	0.084	-0.103	0.115	-0.011	-0.955	1

Where: R^2=coefficient of determination; Coef=coefficients; Std Err=standard error.
Source: SCHRÖDER et al. (2007).

Figure 4-30 visualises the Q-Q plots of the original cw model's residuals, which indicates that rank-based z-scores for model's residual values lower than -2 and higher than 2 have positive and negative deviations from the red trend line. However, the coefficient of determination of z-scores trend line remained very high 0.98. Thus, the distribution of model's residuals was close or equal to normal.

Figure 4-31 visualises the homogeneity of variance of the cw model's residuals. The red Loess nonparametric regression line shows if the model has some serious deviations. The model tends to overestimate, by up to 1 metre, cw values up to 2m and to underestimate by -0.5m cw values in the 2-6m interval. Loess nonparametric regression line visualised remarkable positive and negative deviations of analysed model.

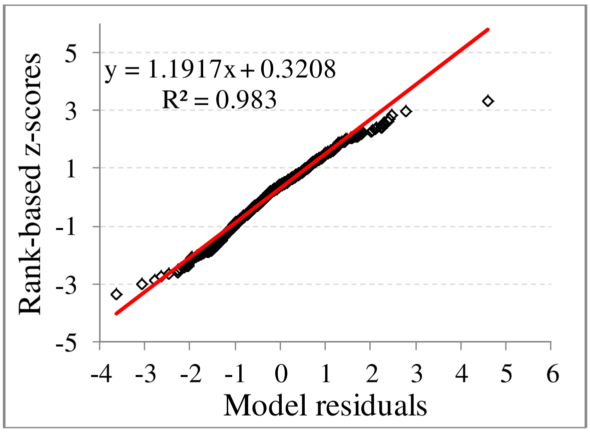


Figure 4-30: Q-Q plots of *SCHRÖDER*^{7OR} crown width (*cw*) model residuals.

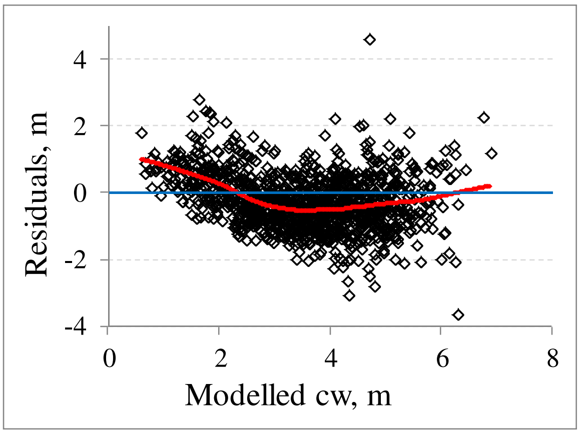


Figure 4-31: Homogeneity of the variance of *SCHRÖDER*^{7OR} crown width (*cw*) model residuals.

To conclude, the coefficient of determination of *SCHRÖDER*^{7OR}*cw* model showed average capacities to predict crown widths of Lithuanian pine trees. Analysis of the Q-Q plots showed normal or close to normal distribution of the model's residuals. Yet, analysis of homogeneity of variance of model's residuals showed remarkable positive and negative deviations of the analysed model. Thus, this model had to be re-parameterised under Lithuanian growth conditions.

The *SCHRÖDER*$^{7OR}i_{ba_5}$ *model.* This model was evaluated by applying the same analysis as for the h_{cb} and cw models. The results of statistical analysis are presented in Table 4-11. The coefficient of determination (R^2) for this model was equal to 0.528. Low inter-correlation of the model's coefficients (lower than 0.8) did not show multicollinearity between them.

Table 4-11: Statistical parameters of $SCHRÖDER^{7OR}i_{ba_5}$ (periodic mean five year basal area increment) model, tested on Lithuanian PEPs.

R^2	Coefficients				Correlation				
	Coef		Value	Std Err		a_0	a_1	a_2	a_3
0.512		a_0	-6.332	0.051	a_0	1	-0.25	-0.40	-0.43
	csa	a_1	0.9171	0.02	a_1	-0.25	1	-0.78	0.62
	MSA	a_2	-0.6208	0.02	a_2	-0.40	-0.78	1	-0.36
	CI_4	a_3	-0.1114	0.002	a_3	-0.43	0.62	-0.36	1
	ΔCI_4	a_4	0	0	a_4				

Where: R^2=coefficient of determination; Coef=coefficients; Std Err=standard error.
Source: SCHRÖDER et al. (2007).

Figure 4-32 visualises the Q-Q plots of $SCHRÖDER^{7OR}i_{ba_5}$ residuals, and indicates the rank-based z-scores for model's residual values lower than -1 and higher than 2 that express positive and negative deviations from the red trend line, respectively. Thus, the distribution of model's residuals hardly could be evaluated as normal, even though the coefficient of determination of z-scores trend line remained high 0.95.

Figure 4-33 shows the homogeneity of variance of this model's residuals. According to the red Loess nonparametric regression line, the model has the tendencies to overestimate the logarithmic modelled i_{ba_5} values by up to 2 in the interval from -11 to -6.86; up to -0.022 for the interval from -6.86 and -6.32, and up to 0.113 in the last interval from -6.32 to -4.47.

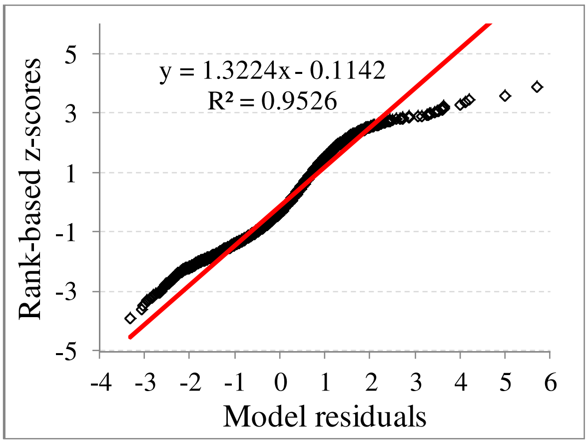


Figure 4-32: Q-Q plots of original $SCHRÖDER^{7OR}$ periodic mean five year basal area increment (i_{ba5}) model residuals.

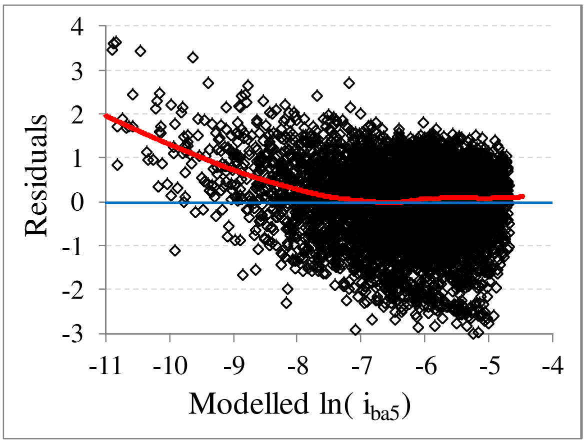


Figure 4-33: Homogeneity of the variance of $SCHRÖDER^{7OR}$ periodic mean five year basal area increment (i_{ba5}) model residuals.

To conclude, the $SCHRÖDER^{7OR}i_{ba_5}$ had average capacities to predict basal area increment of Lithuanian pine trees. The comparably high coefficient of determination showed an average fit of this model to the analysed data. Analysis of the Q-Q plots revealed that the distribution of residuals hardly was normal. Analysis of homogeneity of variance of the model's residuals showed the model's tendency to overestimate the smallest logarithmic i_{ba_5} values or to overestimate very low increments of trees. This model had to be re-parameterised.

4.4.3.2 Re-parameterisation of Saxonian basal area increment model

The SCHRÖDER$^{7ReP}h_{cb}$ model. This nonlinear model was evaluated by testing the following statistical characteristics: model's coefficient of determination (R^2) and multicollinearity of independent variables. Regression assumptions were checked by plotting Q-Q plots and by testing homogeneity of variance of model's residuals.

A very high R^2 value was estimated for this model (0.905). Coefficient a_0 had the highest inter-correlation with coefficient a_3 (-0.80), coefficient a_1 had the highest inter-correlation with coefficient a_2 (0.88), coefficient a_2 had the highest inter-correlation with coefficient a_1 (0.88), and coefficient a_3 had the highest correlation with coefficient a_2 (-0.86). Possible multicollinearity was recorded between coefficients a_1 and a_2, and a_2 and a_3 (Table 4-12).

Table 4-12: Statistical parameters of *SCHRÖDER$^{7ReP}h_{cb}$* (height to crown base) model tested on Lithuanian PEPs.

R^2	Coefficients			Correlation			
	Coef	**Value**	**Std Err**	a_0	a_1	a_2	a_3
0.905	a_0	-1.2747	0.075	1	0.16	0.41	-0.80
	a_1	0.2575	0.048	0.16	1	0.88	-0.71
	a_2	-0.016	0.001	0.41	0.88	1	-0.86
	a_3	0.8367	0.038	-0.80	-0.71	-0.86	1

Where: R^2=coefficient of determination; Coef=coefficients; Std Err=standard error.
Source: SCHRÖDER et al. (2007).

Figure 4-34 describes the Q-Q plots of *SCHRÖDER$^{7ReP}h_{cb}$*'s residuals, which show rank-based z-scores for residual values lower than -3 and higher than 3 have positive and little negative deviation from the red trend line. Yet, coefficient of determination of z-scores trend line remained very high 0.99. According to these results, the distribution of *SCHRÖDER$^{7ReP}h_{cb}$*'s residuals was close or equal to normal.

Figure 4-35 shows the homogeneity of variance of *SCHRÖDER$^{7ReP}h_{cb}$*'s residuals. The red Loess nonparametric regression line shows that *SCHRÖDER$^{7ReP}h_{cb}$* works precisely. Only in 7-12m range of modelled h_{cb} values, does the model have a tendency to overestimate by 0.45m.

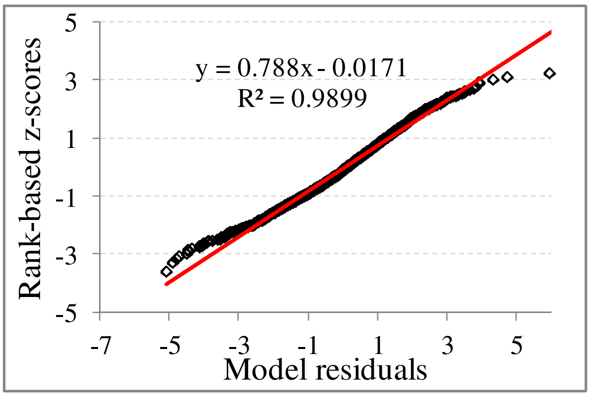


Figure 4-34: Q-Q plots of *SCHRÖDER^{7ReP}* height to crown base (h_{cb}) model residuals.

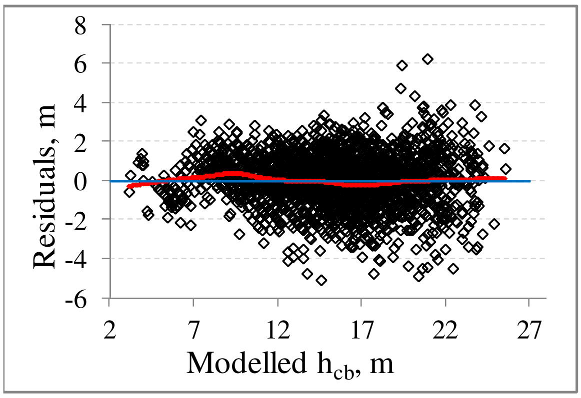


Figure 4-35: Homogeneity of the variance of *SCHRÖDER$^{7ReP}h_{cb}$* model residuals.

To conclude, *SCHRÖDER*$^{7ReP}h_{cb}$ was sufficiently precise to predict h_{cb} of Lithuanian pine trees. According to the statistical analysis, the model was characterised by excellent coefficient of determination value. Analysis of the Q-Q plots showed normal or close to normal distribution of model's residuals. Analysis of homogeneity of variance of model's residuals and Loess nonparametric regression showed no remarkable model's tendencies to underestimate h_{cb} values. So re-parameterisation removed the systematic tendency of *SCHRÖDER*$^{7OR}h_{cb}$ model to underestimate h_{cb} values higher than 12 metres.

SCHRÖDER^{7ReP}*cw model.* This is also a nonlinear model that was evaluated using the same analysis as for the h_{cb} model. The results of the statistical analysis are presented in Table 4-13. The R^2 value for this model was very high 0.692. Coefficient a_0 had very high inter-correlation values with coefficients a_2, a_4 and a_5, respectively, 0.97, 0.98 and -1.00. The coefficient a_1 had the highest inter-correlation with coefficient a_2 (-0.8), and coefficient a_2 had very high inter-correlation values with coefficients a_0, a_4 and a_5, respectively, 0.97, 0.92 and -0.95. Inter-correlations of coefficient a_3 remained comparably low, not lower than -0.51. Coefficients a_4 and a_5 had very high inter-correlation value -0.99. In summary, coefficients a_0, a_2, a_4 and a_5 were multicollinear.

Table 4-13: Statistical parameters of *SCHRÖDER*^{7ReP}*cw* (crown width) model on tested on Lithuanian PEPs.

R^2	Coefficients			Correlation						
	Coef	**Value**	**Std Err**		a_0	a_1	a_2	a_3	a_4	a_5
0.692	a_0	11.359	3.293	a_0	1	-0.74	0.97	-0.51	0.98	-1.00
	a_1	0.1237	0.006	a_1	-0.74	1	-0.80	0.12	-0.74	0.73
	a_2	3.8496	4.887	a_2	0.97	-0.80	1	-0.43	0.92	-0.95
	a_3	0.5776	0.198	a_3	-0.51	0.12	-0.43	1	-0.48	0.48
	a_4	0.0547	0.014	a_4	0.98	-0.74	0.92	-0.48	1	-0.99
	a_5	-1.7571	0.43	a_5	-1.00	0.73	-0.95	0.48	-0.99	1

Where: R^2=coefficient of determination; Coef=coefficients; Std Err=standard error.
Source: SCHRÖDER et al. (2007).

Figure 4-36 visualises the Q-Q plots of *SCHRÖDER*^{7ReP}*cw*'s residuals, which show rank-based z-scores for model's residual values lower than -1.5 and higher than 1.5 have small positive and negative deviations from the red trend line. Yet, the R^2 of z-scores trend line was very high 0.97. Thus, the distribution of *SCHRÖDER*^{7ReP}*cw*'s residuals was close or equal to normal.

Figure 4-37 visualises the homogeneity of variance of *SCHRÖDER*^{7ReP}*cw*'s residuals. According to the red Loess nonparametric regression line, the model's residuals are equally distributed in all range of modelled cw values.

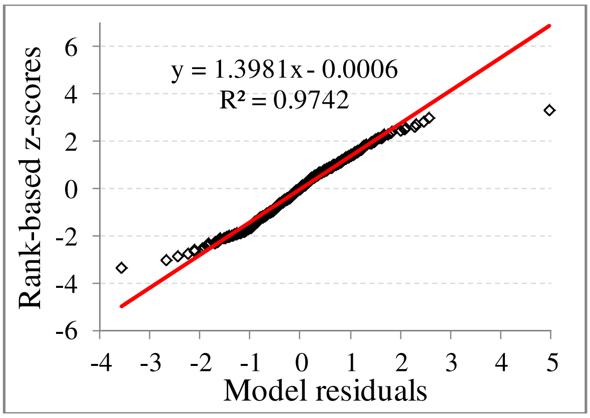


Figure 4-36: Q-Q plots of *SCHRÖDER*^{7ReP} crown width (*cw*) model residuals.

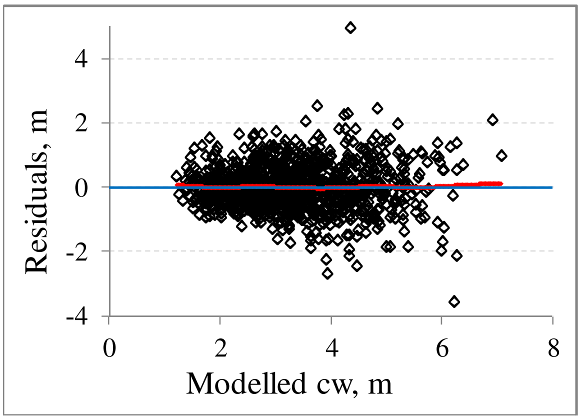


Figure 4-37: Homogeneity of the variance of *SCHRÖDER*^{7ReP} crown width (*cw*) model residuals.

To conclude, *SCHRÖDER*^{7ReP}*cw* had high capacities to predict cw of Lithuanian pine trees. According to the statistical analysis, the model was characterised by high coefficient of determination value. Analysis of Q-Q plots showed normal or close to normal distribution of model's residuals. Analysis of homogeneity of variance of model's residuals and Loess nonparametric regression showed that model's residuals are equally distributed in all range of modelled cw values. So re-parameterisation removed remarkable positive and negative deviations that were found in *SCHRÖDER*^{7OR}*cw* model.

The SCHRÖDER^{7ReP}i_{ba_5} *model.* The parameters for this model were estimated by using multiple linear regression analysis (see subsection 3.10.2). The goodness of fit of the regression model was evaluated by estimating the coefficient of determination (R^2) and by testing the model's statistical significance and its estimated parameters. Multicollinearity was checked by estimating VIF values for each model's parameter. Regression assumptions were checked by visualising Q-Q plots and homogeneity of variance of the model's residuals.

The results of statistical analysis are presented in Table 4-14. The R^2 for *SCHRÖDER*^{7ReP}i_{ba_5} remained comparably high and was equal to 0.572. The *SCHRÖDER*^{7ReP}i_{ba_5} was highly significant, as a consequence of all the independent variables in the model being highly significant. The lowest significance level was recorded for the independent variable MSA that was equal to 8.96×10^{-27}. Partial correlation analysis showed that the most predictive independent variable in this model was crown surface area (csa). Furthermore, VIF statistics did not reveal any multicollinearity between independent variables. The highest VIF value was recorded for csa (2.03).

Table 4-14: Statistical parameters of *SCHRÖDER*$^{7ReP}i_{ba_5}$ (periodic mean five year basal area increment) model tested on Lithuanian PEPs.

R^2	Sign	Coefficients						
		Coef		Value	Std Err	Sign	Partial corr	VIF
0.572	0		a_0	-8.908	0.062	$0.00 \cdot 10^{00}$		
		csa	a_1	1.0819	0.017	$0.00 \cdot 10^{00}$	0.54	2.03
		MSA	a_2	-0.1407	0.013	$8.96 \cdot 10^{-27}$	-0.11	1.33
		CI_4	a_3	-0.0549	0.002	$1.22 \cdot 10^{-200}$	-0.3	1.64
		ΔCI_4	a_4	-	-		-	-

Where: R^2=coefficient of determination; Sign=significance value; Coef=coefficients; Std Err=standard error; Partial corr=partial correlation; VIF=variance inflation factor.
Source: SCHRÖDER et al. (2007).

Q-Q plots of *SCHRÖDER*$^{7ReP}i_{ba_5}$'s residuals, which show rank-based z-scores for model's residual values lower than -1 and higher than 1 have positive deviations from the red trend line (Figure 4-38). Thus, the distribution of the model's residuals cannot really be evaluated as normal, even though the coefficient of determination of z-scores red trend line was 0.94. Figure 4-39 shows the homogeneity of variance of *SCHRÖDER*$^{7ReP}i_{ba_5}$'s residuals. According to the red Loess nonparametric regression line, the model tends: in the interval from -11 to -8.4, to overestimate logarithmic modelled i_{ba_5} values up to 1; in the interval from -8.4 to -6.4, to underestimate logarithmic i_{ba_5} values up to -0.2; in the interval from -6.4 to -5.25, to overestimate logarithmic i_{ba_5} values up to -0.11, and finally, in the interval from -5.25 to -3.86, to underestimate logarithmic i_{ba_5} values by -0.317.

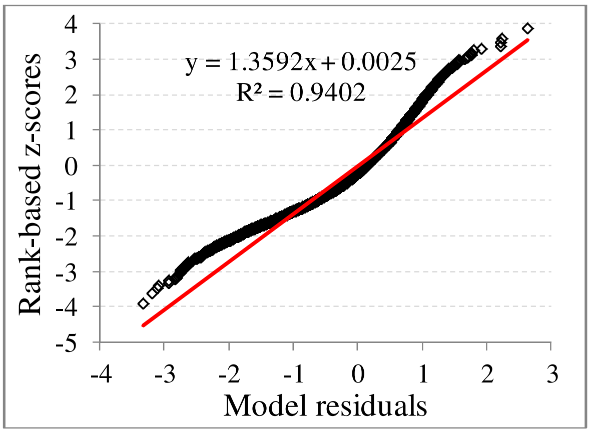


Figure 4-38: Q-Q plots of *SCHRÖDER*^{7ReP} periodic mean five year basal area increment (i_{ba5}) model residuals.

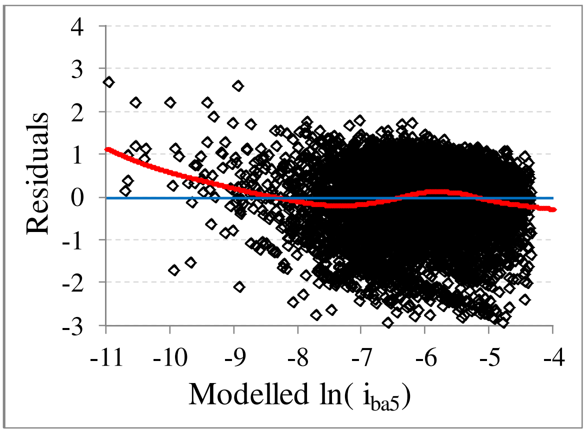


Figure 4-39: Homogeneity of the variance of *SCHRÖDER*^{7ReP} periodic mean five year basal area increment (i_{ba5}) model residuals.

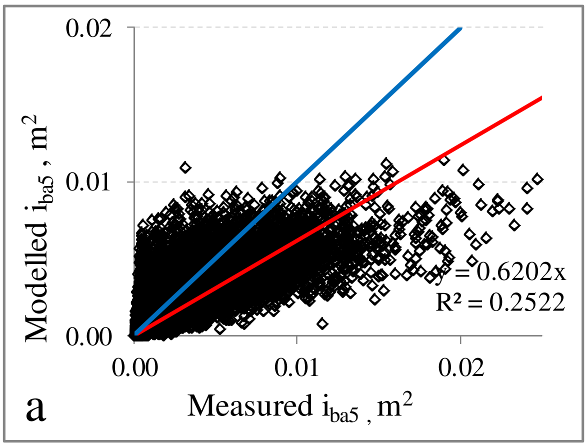
To conclude, *SCHRÖDER*$^{7ReP}i_{ba_5}$ model has good capacities to predict basal area increment of Lithuanian pine trees. Results of statistical analysis showed model's good fit to the analysed data. The coefficient of determination for this model was comparably high. *SCHRÖDER*$^{7ReP}i_{ba_5}$ was highly significant as well as all the independent variables. According to analysis of the

Q-Q plots of the model's residuals, their distribution could hardly be evaluated as normal. Analysis of homogeneity of variance of $SCHRÖDER^{7ReP}i_{ba_5}$'s residuals showed the model's tendency to overestimate smallest logarithmic i_{ba_5} values. However, compared to $SCHRÖDER^{2007OR}i_{ba_5}$, $SCHRÖDER^{7ReP}i_{ba_5}$ reduced this overestimation by half.

According to the results, the initial hypothesis (see Section 4.1) is proven in that a re-parameterised model based on Lithuanian data *does* fit better under Lithuanian conditions regarding basal area increment. Analyses of both $SCHRÖDER^{7OR}$ and $SCHRÖDER^{7ReP}$ models of h_{cb}, cw and i_{ba_5} proved the superiority of $SCHRÖDER^{7ReP}$ to predict the growth of pine trees in Lithuania. Re-parameterisation reduced or eliminated the systematic deviations of the various $SCHRÖDER^{7OR}$ models.

4.4.3.3 The impact of logarithmic transformation to BWINPro-S basal area increment model

Logarithmic transformation introduces a systematic bias, thus when transformed back to normal scale, the correction factor has to be applied to counteract this bias (SPRUGEL 1983). Figure 4-40a, visualises measured i_{ba_5} values against modelled by $SCHRÖDER^{7OR}i_{ba_5}$ model values, this model has a very clear tendency to underestimate i_{ba_5} values. The slope of the coefficient of the trend line with 0 intercept was equal to 0.62. However, inclusion of the transformation factor to Equation 3-40 increased the slope coefficient to 0.83 (Figure 4-40b). In this way, models systematic bias was remarkably decreased. In both cases coefficient of determination (R^2) between measured and modelled i_{ba_5} values was equal to 0.25.



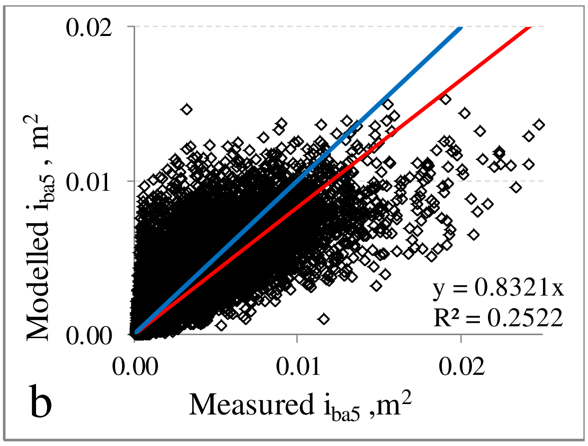
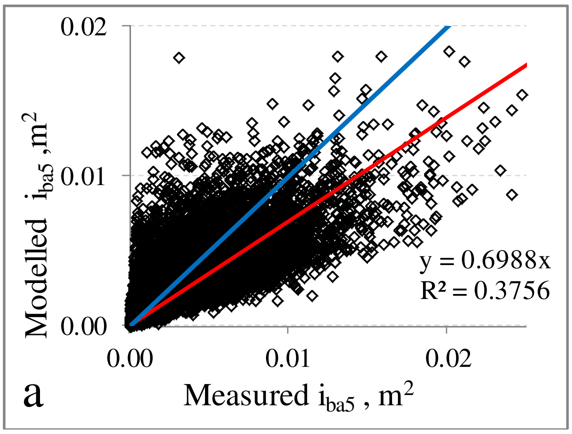


Figure 4-40: Comparison of measured and modelled ($SCHRÖDER^{7OR}$) periodic mean five year basal area increment (i_{ba_5}) values when transformed from logarithmic to normal scale. a) without bias factor, b) with bias factor.

Figure 4-41a visualises measured i_{ba_5} values against modelled by $SCHRÖDER^{7ReP}i_{ba_5}$ values, this model also had clear tendency to underestimate i_{ba_5} values (Figure 4-41a). However this tendency was lower than produced by *SCHRÖDER*$^{7OR}i_{ba_5}$. The slope of the coefficient of the trend line with 0 intercept was equal to 0.699. Inclusion of the transformation factor to Equation 3-40 increased predictions of *SCHRÖDER*$^{7ReP}i_{ba_5}$ (Figure 4-41b). The slope of the trend line with 0 intercept increased to 0.9. In this way *SCHRÖDER*^{7ReP}'s systematic tendency to underestimate i_{ba_5} values was almost eliminated. In both cases the R^2 between measured and modelled i_{ba_5} values was equal to 0.38.



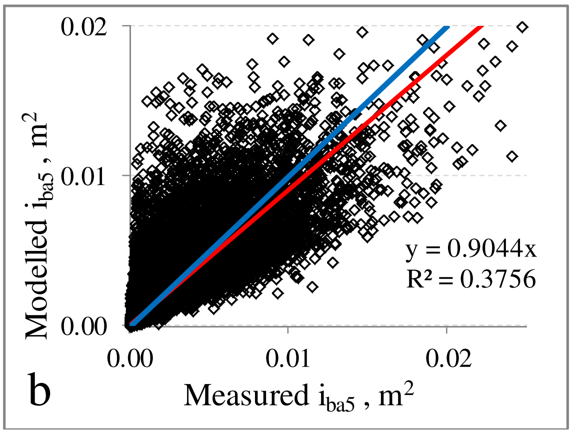


Figure 4-41: Comparison of measured and modelled (*SCHRÖDER*^{7ReP}) periodic mean five year basal area increment (i_{ba_5}) values when transformed from logarithmic to normal scale. a) without bias factor, b) with bias factor.

To conclude, inclusion of the transformation factor improved predictions of both *SCHRÖDER*$^{7OR}i_{ba_5}$ and the *SCHRÖDER*$^{7ReP}i_{ba_5}$ by remarkably reducing negative systematic bias. Transformed and untransformed predictions of *SCHRÖDER*$^{7ReP}i_{ba_5}$ were more precise than *SCHRÖDER*$^{7OR}i_{ba_5}$ with higher coefficient of determination and lower negative bias. Transformation of *SCHRÖDER*$^{7ReP}i_{ba_5}$ also reduced the negative bias to minimum. These results support the formulated hypothesis.

4.4.4 Modelling height increment of trees

4.4.4.1 Comparing mean heights: results of National Forest Inventories

National Forest Inventories (NFI) provide valuable information that describes the growth of trees in the two analysed countries. These results come from many PEPs equally distributed around the countries and are indeed very informative. Thus, the comparison of the results provided by Lithuania's NFI (KULIEŠIS & KULBOKAS 2008) and Saxony's NFI (FEDERAL MINISTRY OF FOOD AND AGRICULTURE 2014) could indicate whether or not growth conditions in Lithuania and Saxony differ.

For this purpose the development of mean stand height (H_q) over the mean stand age (MSA) was used (Figure 4-42). According to this model, up to the age of 25 years, pines in Saxony grow faster than in Lithuania. However, between 25 and 120 years of age, Lithuanian pines exceed Saxony pines by up to 2m. The faster increment of H_q in Saxony in the initial 25 years could be explained by methodological differences that appear in the two NFIs. In Germany's NFI, only those trees with d_{bh} larger than 7cm are taken into account, whereas in Lithuania's NFI, all trees are included. This discrepancy shows that development of H_q over MSA is also influenced by quadratic mean diameter development over MSA. However, since stand top height is not included in Lithuania's NFI a better stand level variable provided by both inventories could not be found.

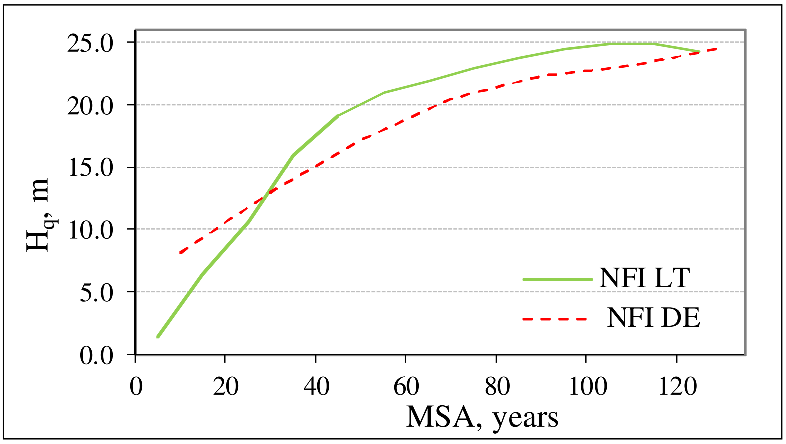


Figure 4-42: Comparison of mean stand height (H_q) development over the mean stand age (MSA). Results of National forest Inventories (NFI) implemented in Lithuania (LT) and Saxony (DE).

To conclude, data of Lithuania's NFI and Saxony's NFI show growth differences of pine trees in the analysed countries. The mean stand height over the age increases faster in Lithuania comparing with Saxony. This is an additional argument showing the need to re-parameterise SCHRÖDER (2004) periodic mean five year height increment model i_{h5}.[3]

4.4.4.2 Developing stand's top height in age 100 years model

The stand top height (H_{100}) is not used as stand characteristic in Lithuania, however, this parameter is very important in $SCHRÖDER^{4OR}i_{h5}$ model. So the H_{100} model will be developed by using data of PEPs of this study. Growth conditions of pine stands also can be compared by evaluating H_{100} and H_q relations in both countries. For this purpose data that come from yield tables of Saxony and data estimated from PEPs in Lithuania will be analysed. With the same H_{100} value, a lower H_q value shows that stands are grown more densely.

[3] Henceforth abbreviations will refer to the original SCHRÖDER 2004 model ($SCHRÖDER^{4OR}$) and the re-parameterised ($SCHRÖDER^{4ReP}$). These abbreviations will prefix the models.

Comparison of German and Lithuanian stand top heights (H_{100}). According to Figure 4-43, the slope (1.0195) of the green trend line that describes H_{100} and H_q relations in Lithuania was steeper than the slope (0.9556) of the red line which presents the results of Saxony. This difference was more remarkable for taller trees, with H_q value higher than 15m.

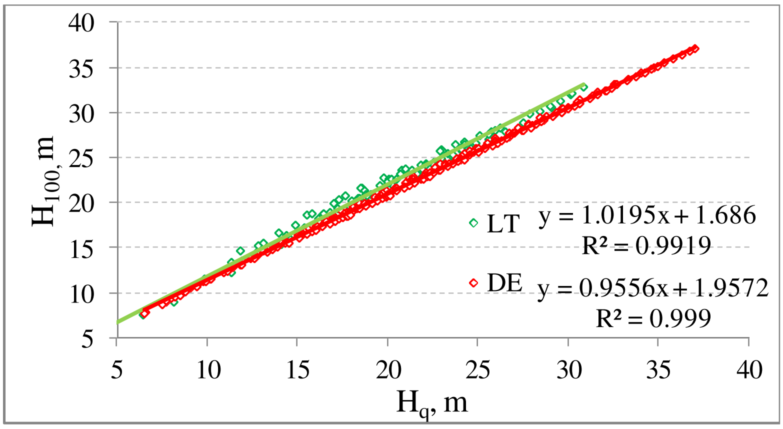


Figure 4-43: Correlation between stand mean height (H_q) and stand top height (H_{100}) based on yield tables of Saxony (DE) (LEMBCKE et al. 2000) and data from PEPs of this study (LT).

The described difference between H_{100} and H_q relations in Lithuanian PEPs and in yield tables of Saxony is an additional argument, supporting the idea of re-parameterisation of *SCHRÖDER*$^{4OR}i_{h5}$.

Constructing the H_{100} model. In the first step, the correlation matrix was constructed to reveal the most relevant independent variables (Table 4-15): mean stand age (MSA), site productivity indexes according to the mean stand height (H_{AB}) and quadratic mean diameter (D_{AB}) at the base age (100 years), the number of growing trees ha^{-1} (N), mean stand height (H_q) and quadratic mean stand diameter (D_q).

The highest positive correlations were estimated between H_{100} and H_q (0.996), D_q (0.96) and MSA (0.85) see Table 4-15. By contrast, the highest estimated negative correlation was N (-0.91) and the weakest positive correlation H_{AB} (0.34). Finally, almost no correlation was found with D_{AB} (-0.02).

Table 4-15: The correlation matrix of stand top height and the main stand level independent variables.

	H_{100}	MSA	H_{AB}	D_{AB}	N	H_q	D_q
H_{100}	1	0.85*	0.34*	-0.02	-0.91*	0.996*	0.96*
MSA		1	-0.12	-0.33*	-0.84*	0.84*	0.88*
H_{AB}			1	0.83*	-0.12	0.38*	0.32*
D_{AB}				1	0.17	0.04	0.09
N					1	-0.89*	-0.89*
H_q						1	0.97**
D_q							1

Where: H_{100}=stand top height in m; MSA=mean stand age in years; H_{AB} and D_{AB}=site productivity indices according to the mean stand height and quadratic mean diameter at base age in m and in cm; N=number of growing trees ha^{-1}; H_q=mean stand height in m; D_q=quaratic mean diameter in cm.
* Correlation is significant at the 0,05 level (2-tailed), ** Correlation is significant at the 0,01 level (2-tailed).

The correlation matrix reveals possible multicollinearity between the independent variables. For example, variables H_q, D_q, N and MSA have very high inter-correlations that are higher than 0.84 or lower than -0.89. Also, high inter-correlation (0.83) was recorded between H_{AB} and D_{AB}. However, these variables had low correlations with other independent variables (not higher than 0.38 and not lower than -0.33). Thus, the most appropriate variables to model H_{100} are H_q and H_{AB}. H_q has the highest correlation with H_{100} and H_{AB} is not multicollinear with the other analysed independent variables.

During the statistical analysis, various model types were tested (linear, exponential and parabolic). However, the model with logarithmic transformations of H_{100}, H_q and H_{AB} variables was recognized to be the best one (Equation 4-3).

$$\ln H_{100} = 0.922 \cdot \ln H_q - 0.0935 \cdot \ln H_{AB} + 0.642 \tag{4-3}$$

Where: H_{100}=stand top height in m; H_q=stand mean height in m; H_{AB}=site productivity index according to the mean stand height at base age in m; ln=natural logarithm.

This model was evaluated by estimating the coefficient of determination (R^2), the statistical significance of model and its estimated parameters, VIF, normal distribution as well as homogeneity of variance of the model's residuals.

According to the results, this model has very high R^2 value equal to 0.997 (Table 4-16) and was highly significant with a value equal to $1.6x10^{-125}$. All the model's coefficients were highly significant and the VIF test did not show any multicollinearity between the analysed independent variables (1.05<4).

Table 4-16: Statistical parameters of multiple stand top height regression model.

R^2	Sign	Coef		Value	Std Err. Coef	Sign	Partial corr	VIF
0.997	1.6E-125	Const	a_0	0.6420	0.052	6.7E-22		
		$\ln(H_q)$	a_1	0.9220	0.005	8.4E-126	0.998	1.05
		$\ln(H_{AB})$	a_2	-0.0935	0.016	9.44E-08	-0.50	1.05

Where: R^2=coefficient of determination; Sign=significance value; Coef=coefficients; Std Err=standard error; Partial corr=partial correlation; VIF=variance inflation factor; Const=constant.

Figure 4-44 shows the Q-Q plots of H_{100} model's residuals, indicating rank-based z-scores for model's residual values lower than -3 and higher than 3 have some positive deviations from the trend line. Yet, the distribution of the residuals was close or equal to normal (R^2=0.985).

Figure 4-45 shows the homogeneity of variance of H_{100} model's residuals. According to the red Loess nonparametric regression line, the model in the interval from 1 to 1.5 tends to overestimate modelled H_{100} values up to 0.015. In the interval from 1.5 to 2.7 it tends to underestimate up to -0.025. In the interval from 2.7 to 3.01 it tends to overestimate by 0.0075, and in the interval from 3.01 to 3.4 to underestimate H_{100} values by -0.003.

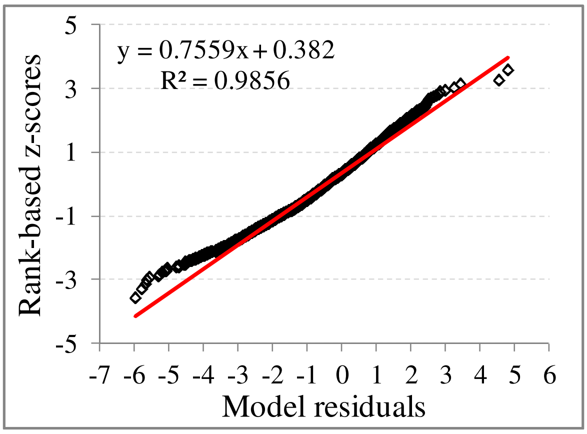


Figure 4-44: Q-Q plots of stand top height (H_{100}) model residuals.

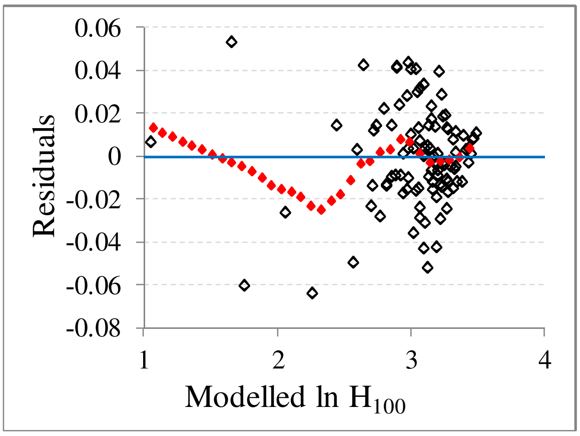


Figure 4-45: Homogeneity of the variance of stand top height (H_{100}) model residuals.

Results of statistical analysis show that the developed logarithmic H_{100} model had very high capacities to predict stand top height from mean stand height and site productivity index (i.e. mean stand height at a base age). By applying this model, stand top height was estimated for Lithuanian yield tables (KULIEŠIS 1993).

4.4.4.3 Re-parameterisation of Saxonian height increment model

Re-parameterisation of $SCHRÖDER^{4OR}i_{h5}$ requires two formulas for Lithuanian growth conditions: H_{100} model for Lithuanian yield tables and relative height increment model.

Re-parameterisation of $SCHRÖDER^{4OR}H_{100}$ *model to create* $SCHRÖDER^{4ReP}H_{100}$. With estimation of H_{100} values, Lithuanian yield tables had all required variables for developing $SCHRÖDER^{4ReP}H_{100}$ model and thus, re-parameterisation was possible using nonlinear regression methods. $SCHRÖDER^{4ReP}H_{100}$ is presented below in Equation 4-4.

$$H_{100} = 81.1963 - 71.6316 \cdot \ln(MSA) + 19.6812 \cdot (\ln(MSA))^2 - 0.6083 \cdot H_{100\_AB} + 0.35 \cdot \ln(MSA) \cdot H_{100\_AB} - 1.7287 \cdot (\ln(MSA))^3 \quad (4\text{-}4)$$

Where: H_{100}=stand top height in m; MSA=mean stand age, in years; H_{100_AB}=stand top height at base age (100 years) in m.

The results of the statistical analysis are presented in Table 4-17. Since $SCHRÖDER^{4ReP}H_{100}$ was constructed from other parameters than those used in Lithuanian yield tables, the coefficient of determination R^2 was very high (0.999). The correlation matrix revealed that some model coefficients have too high correlations, for example a_1 and a_5 (-0.96), a_2 and a_1 (-1), a_3 and a_4 (-0.99).

Table 4-17: Statistical parameters of *SCHRÖDER*$^{4OR}H_{100}$ (stand top height) model.

R^2	Coefficients			Correlation					
	Coef	**Value**	**Std Err**	a_0	a_1	a_2	a_3	a_4	a_5
0.999	a_0	81.1963	2.649	1.00	-0.99	0.97	-0.45	0.45	-0.96
	a_1	-71.6316	2.061		1.00	-1.00	0.32	-0.32	0.99
	a_2	19.6812	0.546			1.00	-0.25	0.25	-1.00
	a_3	-0.6083	0.016				1.00	-0.99	0.23
	a_4	0.3500	0.004					1.00	-0.23
	a_5	-1.7287	0.048						1.00

Where: R^2=coefficient of determination; Std Err=standard error.
Source: SCHRÖDER (2004).

Figure 4-46 shows the Q-Q plots of *SCHRÖDER*$^{4ReP}H_{100}$'s residuals. Rank-based z-scores for model's residual values lower than -0.3 and higher than 0.3 have some positive deviations from the red trend line. However, the coefficient of determination R^2 of z-scores trend line was very high 0.986. Thus, the distribution of the model's residuals was close or equal to normal.

Figure 4-47 shows the homogeneity of variance of *SCHRÖDER*$^{4ReP}H_{100}$'s residuals. It also indicates the non-random distribution of residuals.

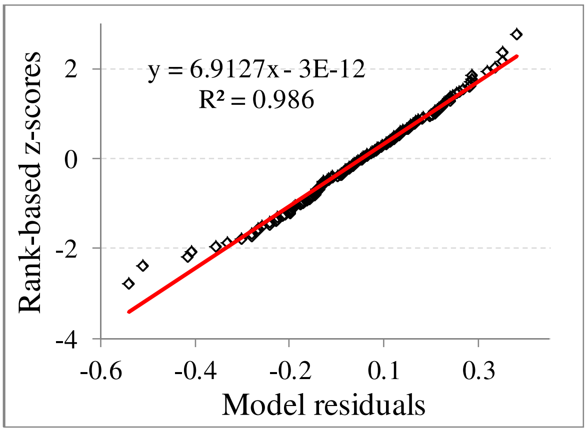


Figure 4-46: Q-Q plots of *SCHRÖDER*$^{4ReP}H_{100}$ model residuals.

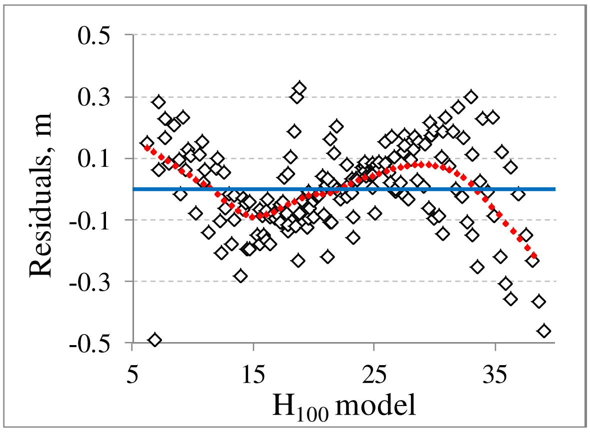


Figure 4-47: Homogeneity of the variance of *SCHRÖDER*$^{4ReP}H_{100}$ model residuals.

To summarise, the statistical analysis of *SCHRÖDER*$^{4ReP}H_{100}$, showed that this model well represents stand top heights of Lithuanian yield tables. This conclusion is based on the very high coefficient of determination. Yet, uneven and unhomogeneous distribution of model's residuals has to be taken into account while modelling.

Comparison of SCHRÖDER$^{4OR}H_{100}$ *and SCHRÖDER*$^{4ReP}H_{100}$ *models.* Figure 4-48 visualises the stand top height model used in Saxony (*SCHRÖDER*$^{4OR}H_{100}$) and the model re-parameterised for Lithuanian growth conditions (*SCHRÖDER*$^{4ReP}H_{100}$).

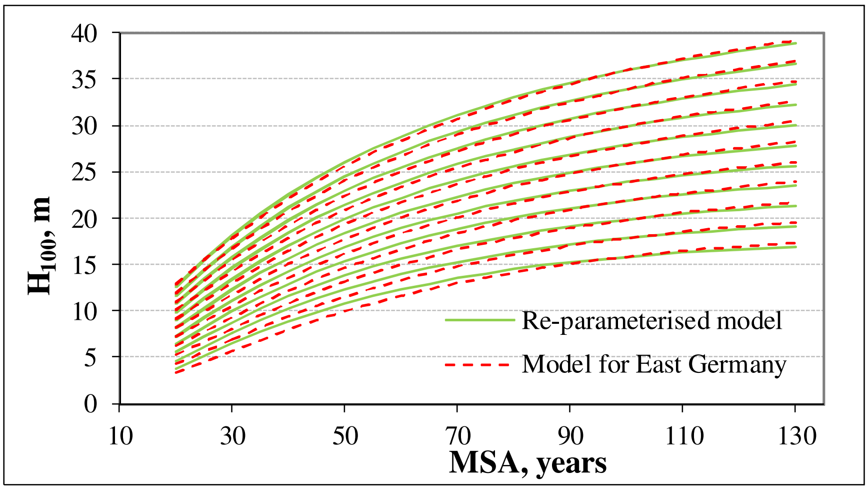


Figure 4-48: Comparison of *SCHRÖDER*$^{4OR}H_{100}$ and *SCHRÖDER*$^{4ReP}H_{100}$ models.

The visualised curves cover a stand's top height at the base age in the interval 16-36m with an increment step of 2m for each curve. This figure for Saxony shows curves are little bit steeper than re-parameterised curves. It means that in Lithuania, trees grow faster in younger age, yet in later stages pines of Saxony demonstrates higher growth rates.

Re-parameterisation of SCHRÖDER$^{4OR}i_{h5}$ *model to create SCHRÖDER*$^{4ReP}i_{h_{rel}}$. The re-parameterised nonlinear model is presented in Equation 4-5.

$$i_{h_{rel}} = i_{H_{rel\_pot}} + 0.0107 \cdot \left(\frac{H_{100}}{h}\right)^{0.5607} + \varepsilon_{rand} \qquad (4\text{-}5)$$

Where: $i_{h_{rel}}$=relative tree height increment; $i_{H_{rel\_pot}}$=relative potential stand top height increment; H_{100}=stand top height in m; h=tree height in m; ε_{rand}=random figure allowing for chance of variation.

The main statistical parameters of this model can be found in Table 4-18, which shows the model was defined by the high coefficient of determination value R^2 (0.812). Interestingly, *SCHRÖDER*$^{4ReP}i_{h_{rel}}$'s coefficients had low inter-correlation value (-0.6).

Table 4-18: Statistical parameters of *SCHRÖDER*$^{4ReP}i_{hrel}$ (relative height increment) model.

R^2		Coefficients		Correlation	
		Value	Std Err	a0	a1
0.812	a_0	0.0107	0.002	1.00	-0.60
	a_1	0.5607	0.558	-0.60	1.00

Where: R^2=coefficient of determination; Std Err=standard error.
Source: SCHRÖDER (2004).

The re-parameterisation of relative tree height increment model was the last step in re-parameterisation of *SCHRÖDER*$^{4OR}i_{h5}$ model. Thus, it is possible to answer the formulated hypothesis concerning height increment models. It was hypothesized that "Re-parameterised height increment model based on Lithuanian data fits better under Lithuanian conditions".

The formulated hypothesis is supported by following results. The comparison of Lithuanian and Saxonian yield tables shows that mean stand heights at $Y^{1\text{-}40}$age increase faster in Lithuania than in Saxony. The data of the National Forest Inventories revealed the same pattern. Comparisons of stand top height and mean stand height relations described by the data of the yield tables of Saxony and data estimated from the PEPs in Lithuania also showed significant distinctions. However, no direct statistical analysis was done to check *SCHRÖDER*^{4OR} height increment model.

4.4.5 Modelling natural mortality of trees

This section consists of three subsections. In the first, variables that predict natural tree mortality with the highest precision are selected and logistic mortality models were developed. In the second, *SCHRÖDER*^{7OR} and *SCHRÖDER*^{7ReP} logistic models were compared to predict natural tree mortality (NTM) of Lithuanian pine trees.[4] In the last subsection, mortality likelihood (ML) functions were developed and compared for each logistic mortality model. Finally, the hypothesis stating that “A re-parameterised model based on Lithuanian data fits better under Lithuanian conditions regarding mortality” was answered.

4.4.5.1 Development of natural mortality logistic functions

In this subsection, the following variables were checked to predict natural tree mortality: 1) distance dependent CIs, 2) tree level variables that indicate individual vitality and 3) stand level variables, which allowed new logistic models to be developed.

Evaluation of distance dependent CIs. Table 4-19 provides the main results. The predictive capability of each variable was estimated by using the following characteristics: result of Chi-square; model’s significance; -2 Log likelihood value; Cox and Snell as well as Nagelkerke coefficients of determination; and percentage correctly classified from the total. The most informative variable is the total correct classification of growing and dead trees. Thus, it will be analysed in detail. Table 4-19 shows the rankings of CI/selection method combinations correctly classifying (%) of the total dead and growing trees. The first is CI_6 with HCB 80 correctly classifying 82.84%; second is CI_7 with HCB 80 correctly classifying 82.15%, third is CI_6 with HWCW 60 correctly classifying 81.68% and the last is CI_4 with SB 60 correctly classifying 58.11%.

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[4] Henceforth abbreviations will refer to these logistic models of natural tree mortality (NTM) of SCHRÖDER et al. (2007) as *SCHRÖDER*$^{7OR}_{NTM}$ (for the original) and *SCHRÖDER*$^{7RP}_{NTM}$ (for the re-parameterised).

Table 4-19: The analysis of competition indices to predict natural tree mortality.

Rank	Selection method	CI	Chi-square	Sign	-2 Log likelihood	Cox and Snell R^2	Nagelkerke R^2	Percentage correct total %
1	HCB 80	CI_6	684.0	0.000	1109.75	0.411	0.547	82.84%
2	HCB 80	CI_7	679.6	0.000	1114.13	0.409	0.545	82.15%
3	HWCW 60	CI_6	613.3	0.000	1180.441	0.377	0.503	81.68%
4	HCB 80	CI_5	541.3	0.000	1252.442	0.342	0.456	80.91%
5	HWCW 60	CI_3	629.7	0.000	1164.042	0.385	0.514	80.83%
6	HCB 80	CI_3	655.2	0.000	1138.545	0.397	0.530	80.76%
7	HWCW 60	CI_7	615.7	0.000	1178.04	0.379	0.505	80.60%
8	HWCW 60	CI_4	537.7	0.000	1255.985	0.340	0.453	80.45%
9	HCB 80	CI_4	624.5	0.000	1169.197	0.383	0.510	80.22%
10	SB 60	CI_3	647.6	0.000	1146.106	0.394	0.525	79.44%
11	HWCW 60	CI_5	353.5	0.000	1440.169	0.239	0.319	77.59%
12	SB 60	CI_6	444.9	0.000	1348.806	0.291	0.388	75.73%
13	SB 60	CI_7	434.1	0.000	1359.598	0.285	0.380	75.27%
14	HWCW 60	CI_8	245.5	0.000	1548.164	0.173	0.230	66.69%
15	HCB 80	CI_8	185.5	0.000	1608.214	0.134	0.178	63.68%
16	SB 60	CI_8	43.9	0.000	1749.767	0.033	0.045	59.12%
17	SB 60	CI_5	53.9	0.000	1739.86	0.041	0.054	58.58%
18	SB 60	CI_4	50.3	0.000	1743.443	0.038	0.051	58.11%

Where: HCB 80=selection method height to crown base with opening angle of 80 degrees; HWCW 60=selection method of height to widest crown width with opening angle of 60 degrees; SB 60=selection method stem base with opening angle of 60 degrees; $CI_1..CI_8$=Competition indices (see Table 3-3); Sign=significance value.

To conclude, distance dependent CIs had very high capabilities to predict natural mortality. The combination of CI_6 with the selection method HCB 80 showed the best results, and was therefore used to construct the logistic model.

Evaluation of tree vitality indicating variables. In the next step, variables that indicate vitality of trees have been evaluated by using the same characteristics as for distant dependent CIs (Table 4-20). The ranking of the most influential variables to correctly predict (%) natural tree mortality (NTM) are: first, d_{bh} over D_q (d_{bh}/D_q), correctly predicting 81.91% of NTM; second, h/d_{bh} correctly predicting 80.48% of NTM; third, periodic mean annual tree basal area increment in previous inventory period (i_{ba_p}) correctly predicting 79.86% of NTM. These variables could be classified as having 'high predictive capacity' correctly predicting 80% (+/-1%) of total growing and dead trees status – [natural tree mortality NTM]. The variables h/H_q, cw, CI_2, ba/BA, $\ln(d_{bh})$, d_{bh}, ba, d_{bh}^2, i_{ba_p}/d_{bh}, $1/d_{bh}$, i_{d_p} have mean predictive capacity, correctly predicting 70-80%, and the variables h, h_{cb}, cr, ${}_ih_p/h$, i_{h_p}, CI_1 have low or no predictive capacity, correctly predicting 44.75-69.44%.

Table 4-20: The influence of tree's vitality indicating variables to prediction of natural tree's mortality.

Independent variable	Chi-square	Sign	-2 Log likelihood	Cox and Snell R^2	Nagelkerke R^2	Percentage correct total %
d_{bh}/D_q	1306.7	0.000	2286.488	0.396	0.528	81.91
h/d_{bh}	1242.1	0.000	2351.053	0.381	0.508	80.48
i_{ba_p}	1060.9	0.000	2532.286	0.336	0.448	79.86
h/H_q	170.7	0.000	520	0.285	0.384	78.80
cw	996.5	0.000	2596.664	0.319	0.426	77.35
CI_2	984.5	0.000	2608,687a	0.316	0.421	76.23
ba/BA	757.8	0.000	2835.389	0.253	0.338	74.50
$\ln(d_{bh})$	919.0	0.000	2674.163	0.299	0.398	74.34
d_{bh}	870.5	0.000	2722.644	0.285	0.380	74.00
ba	714.0	0.000	2879.172	0.241	0.321	73.65
d_{bh}^2	714.0	0.000	2879.172	0.241	0.321	73.65
i_{ba_p}/d_{bh}	799.7	0.000	2793.428	0.265	0.354	73.00
$1/d_{bh}$	724.1	0.000	2869.001	0.244	0.325	72.96
i_{d_p}	627.6	0.000	2965.534	0.215	0.287	70.14
h	580.3	0.000	3012.886	0.201	0.267	69.44
h_{cb}	462.8	0.000	3130.329	0.164	0.218	67.01
cr	251.1	0.000	3342.011	0.092	0.123	66.78
i_{h_p}/h	98.9	0.000	3494.247	0.037	0.050	65.12
i_{h_p}	33.4	0.000	3559.728	0.013	0.017	50.85
CI_1	2.3	0.128	3590,838a	0.001	0.001	44.75

Where: d_{bh}=tree diameter at breast height in cm; i_{ba_p}=periodic mean annual tree basal area increment in previous inventory period [cm^2]; h=tree height in m; cw=crown width in m; i_{d_p}=periodic mean annual tree diameter increment in previous inventory period in cm; ba=tree basal area [m^2]; h_{cb}=tree height to crown base in m; i_{h_p}=periodic mean annual tree height increment in previous inventory period in m; cr=crown ratio; D_q=quadratic mean diameter of remaining stand in cm; BA=basal area of remaining stand [m^2]; CI_1 and CI_2=distance independent competition indices (see Table 3-3); Sign=significance value.

To conclude, variables that indicate vitality of trees could have high, mean, low or even no predictive capacity to define natural mortality. The constructed NTM models should be based on the variables with the highest predictive capacity d_{bh}/D_q, h/d_{bh} and i_{ba_p}.

Evaluation of stand level variables. The predictive capacity of stand level variables was checked by using the same criteria as for evaluating CIs and for evaluating variables indicating individual vitality. The stand level variable with the highest predictive capacity was MSA, predicting 67.55% of total correct classifications. The stand level variables of the next rank were D_q, H_{100}, H_q, N and D_q/D_{AB} all predicting about 66% of total correct classifications. The variable basal area of remaining stand (BA) predicted 54.40% of total correct classifications (Table 4-21).

Table 4-21: The influence of stand level variables on prediction of natural mortality.

Independent variable	Chi-square	Sign	-2 Log likelihood	Cox and Snell R^2	Nagelkerke R^2	Percentage correct total %
			Mean stand variables			
MSA	384.1	0.000	3209.005	0.138	0.184	67.55
D_q	380.3	0.000	3212.895	0.136	0.182	66.63
H_{100}	339.8	0.000	3253.322	0.123	0.164	66.28
H_q	341.2	0.000	3251.955	0.123	0.164	66.24
N	360.4	0.000	3232.787	0.130	0.173	66.20
D_q/D_{AB}	370.2	0.000	3222.992	0.133	0.177	66.20
V	231.4	0.000	3361.744	0.085	0.114	62.42
H_{AB}	94.4	0.000	3498.776	0.036	0.048	60.65
BA	39.5	0.000	3553.623	0.015	0.020	54.40

Where: D_q=quadratic mean diameter of remaining stand in cm; D_{AB}=site productivity index according to the stand mean diameter at the base age (100 years) in cm; N=the number of growing trees ha^{-1}; V=standing volume [m^3 ha^{-1}]; MSA=mean stand age in years; H_{100}=mean height of 100 largest trees ha^{-1} or stand top height in m; H_q=mean stand height in m; H_{AB}=site productivity index according to the mean stand height at the base age (100 years) in m; BA=basal area of remaining stand [m^2]; Sign=significance value.

To summarise, stand level variables showed a generally low capacity to predict NTM. As the variation in predicting capacity of the first six variables was less than 1.4%, the study deemed, MSA, D_q, H_{100}, H_q, N, and D_q/D_{AB} to be potential variables for use in the NTM model.

Development of logistic functions. As a result of detailed statistical analysis of various combinations of independent variables, two NTM models to estimate tree vitality indicating the value (F) were developed. The first model is distance dependent (Equation 4-6) and second model is distance independent (Equation 4-7).

$$F_1 = \frac{1}{1+e^{\left(-\left(-2.2255+0.0367\cdot MSA+5.4092\cdot\frac{i_{ba_p}}{d_{bh}}-0.0539\cdot HCB\,80CI_6\right)\right)}} \tag{4-6}$$

Where: F=tree vitality indicating value; MSA=mean stand age in years; i_{ba_p}=periodic mean annual tree basal area increment in previous inventory period [cm^2]; d_{bh}=tree diameter at breast height in cm; HCB80 CI_6=distance dependent CI_6 (see Table 3-3) combined with selection method HCB 80.

$$F_2 = \frac{1}{1+e^{\left(-\left(-5.2882+3.1624\cdot\frac{D_q}{D_{AB}}+6.3279\cdot i_{d_p}+3.1920\cdot\frac{d_{bh}}{D_q}\right)\right)}} \tag{4-7}$$

Where: F=tree vitality indicating value; i_{d_p}=periodic mean annual tree diameter increment in previous inventory period in cm; d_{bh}=tree diameter at breast height in cm; D_q=quadratic mean diameter of remaining stand in cm; D_{AB}=site productivity index according to the stand mean diameter at base age (100 years) in cm.

The evaluation of each independent variable and estimated coefficients used in the model F_1 and F_2 is presented in Table 4-22, which indicates that all the coefficients of model F_1 and model F_2 were highly significant. Wald statistics showed that the highest predictive capacity in model F_1 was 90.9 for the independent variable i_{ba_p}/d_{bh}, whereas the highest predictive capacity in model F_2 was 155.72 for the independent variable i_{d_p}. Thus, tree increment in the previous growth period, i_{d_p}, is one of the strongest variables to predict NTM.

Table 4-22: Evaluation of coefficients of developed logistic models.

Model	Variables	Coefficients	Value	SE	Wald	Sign
F_1		a_0	-2.2255	0.361	37.92	7.38E-10
	MSA	a_1	0.0367	0.004	84.40	4.04E-20
	i_{ba_p}/d_{bh}	a_2	5.4092	0.567	90.90	1.51E-21
	HCB80 CI_6	a_3	-0.0539	0.008	41.08	1.46E-10
F_2		a_0	-5.2882	0.206	659.36	2.06E-145
	D_q/D_{AB}	a_1	3.1624	0.296	113.91	1.37E-26
	i_{d_p}	a_2	6.3279	0.507	155.72	9.74E-36
	d_{bh}/D_q	a_3	3.1920	0.287	123.94	8.7E-29

Where: MSA=mean stand age in years; i_{ba_p}=periodic mean annual tree basal area increment in previous inventory period [cm^2]; d_{bh}=diameter at breast height in cm; HCB80 CI_6=distance dependent CI_6 (see Table 3-3) combined with selection method HCB 80; D_q=quadratic mean diameter of remaining stand in cm; D_{AB}=site productivity index according to the stand mean diameter at the base age (100 years) in cm; i_{d_p}=periodic mean annual tree diameter increment in previous inventory period in cm; SE=standard error; Sign=significance value.

To reveal the multicollinearity between the independent variables in model F_1 and F_2, correlation matrices for each model are presented (Table 4-23). The highest inter-correlation value of 0.55 in Model F_1 was between the independent variables i_{ba_p}/d_{bh} and HCB 80 CI_6, and the highest inter-correlation value of 0.6 in Model F_2 was for independent variables i_{d_p} and D_q/D_{AB}. Low inter-correlation values indicate no multicollinearity between independent variables in the analysed models.

Table 4-23: Evaluation of inter-correlation between independent variables.

Model F_1					**Model F_2**				
	Const	**HCB 80 CI_6**	**i_{ba_p}/d_{bh}**	**MSA**		**Const**	**d_{bh}/D_q**	**i_{d_p}**	**D_q/D_{AB}**
Const	1	-0.75	-0.83	-0.83	**Const**	1	-0.42	-0.37	-0.42
HCB 80 CI_6		1	0.55	0.48	**d_{bh}/D_q**		1	-0.49	-0.57
i_{ba_p}/d_{bh}			1	0.53	**i_{d_p}**			1	0.60
MSA				1	**D_q/D_{AB}**				1

Where: Const=constant; HCB80 CI_6=distance dependent CI_6 (see Table 3-3) combined with selection method HCB 80; i_{ba_p}=periodic mean annual tree basal area increment in previous inventory period [cm^2]; d_{bh}=tree diameter at breast height in cm; D_{AB}=site productivity index according to the stand mean diameter at the base age (100 years) in cm; D_q=quadratic mean diameter of remaining stand in cm; i_{d_p}=periodic mean annual tree diameter increment in previous inventory period in cm; MSA=mean stand age in years.

The evaluation of the predictive capacity of models F_1 and F_2 is presented in (Table 4-24). Chi-square test values and log likelihood values for model F_1 are lower due to the removal of border trees in the distance dependent analysis. Thus, these parameter values are not comparable with model F_2 values. However other parameters such as coefficients of determination values could be compared. Model F_1 scored higher with Cox and Snell (0.47 v 0.44) as well as Nagelkerke R^2 (0.63 v 0.59).

Table 4-24: Statistical parameters of developed logistic models.

Model	Chi-square	Sign	-2 Log likelihood	Cox and Snell R^2	Nagelkerke R^2	ROC area	Percentage correct		
							1	0	Total
F_1	829.80	0.00	963.92	0.47	0.63	0.915	84.53	83.94	84.23
F_2	1507.02	0.00	2086.14	0.44	0.59	0.902	83.07	83.37	83.22

Where: Sign=significance.

The percentage of correctly predicted statuses for growing and dead trees was higher for model $F_{1,}$ which scored the 84.53% for growing trees 84.53% and 83.94% for dead trees and 84.23% overall. The Model F_2 managed to correctly predict 83.07% of growing trees and 83.37% of dead trees, and 83.22% overall.

The largest area under the receiver operating characteristic (ROC) curve was for model F_1, equal to 0.915; the ROC area for model F_2 was only slightly smaller, at 0.902. The ROC had rapidly increasing exponential shape showing models' high predictive capacities of natural mortality (Figure 4-49a and b).

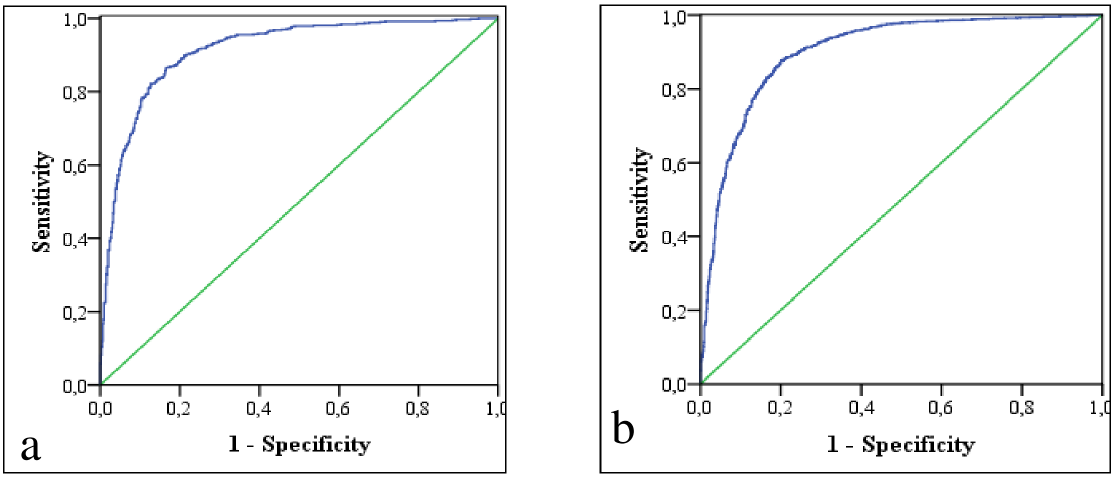

Figure 4-49: Visualisation of ROC curves. (a) F_1 model (b) F_2 model. The blue line is a ROC curve, green line y=x curve (Indicates no discrimination).

To conclude, two NTM models, developed by this study, showed very high capacity to predict natural morality of trees. However, the distance dependent NTM model scored better results in the statistical analysis than the distance independent model; although the difference between the distance dependent and distance independent models was very small.

4.4.5.2 Evaluation of BWINPro-S natural mortality logistic functions

The other very important part of this study was the evaluation of $SCHRÖDER^{7OR}{}_{NTM}$ used in BWINPro-S. The first step involved re-parameterising $SCHRÖDER^{7OR}{}_{NTM}$ by applying data from Lithuanian PEPs to create *SCHRÖDER*$^{7ReP}_{NTM}$. The next step was to evaluate *SCHRÖDER*$^{7OR}_{NTM}$ and *SCHRÖDER*$^{7ReP}_{NTM}$ by applying logistic regression methods (see subsection 3.10.4).

Re-parameterisation of SCHRÖDER$^{7OR}_{NTM}$ *to create SCHRÖDER*$^{7ReP}_{NTM}$. The fully re-parameterised NTM model (*SCHRÖDER*$^{7ReP}_{NTM}$) for estimating tree vitality indicating value (F) is presented in Equation 4-8.

$$F = \frac{1}{1+e^{\left(-\left(0.4694+0.1123\cdot d_{bh}+3.7130\cdot\frac{i_{ba_p}}{d_{bh}}-2.5575\cdot\frac{h}{d_{bh}}\right)\right)}} \qquad (4\text{-}8)$$

Where: F=tree vitality indicating value; d_{bh}=tree diameter at breast height in cm; h=tree height in m; i_{ba_p}=periodic mean annual tree basal area increment in previous inventory period [cm^2].

According to the results, coefficient a_1 had the highest Wald statistics value (154.81). Thus, in this formula the most important independent variable is d_{bh}. All independent variables included into the equation were highly significant. Multicollinearity between independent variables was not found, since the highest inter-correlation recorded between i_{bap}/d_{bh} and h/d_{bh} was equal to 0.6.

Table 4-25 presents the main results of the statistical analysis of the re-parameterised F model, *SCHRÖDER*$^{7ReP}_{NTM}$ as presented above. The model's independent variables and their coefficients are described by standard error, Wald statistics and significance level values. Alongside the 'evaluation of coefficients' is the correlation matrix checking the inter-correlation between independent variables.

According to the results, the highest Wald statistics value had coefficient a_1 (154.81). Thus, in this formula the most important independent variable is d_{bh}. All independent variables, included in the equation, were highly significant. Multicollinearity between independent variables was not found, since the highest inter-correlation recorded between i_{ba_p}/d_{bh} and h/d_{bh} was 0.6.

Table 4-25: Evaluation of coefficients of *SCHRÖDER*^{7ReP} logistic model.

Variable	Coef	Value	SE	Wald	Sign	Correlation matrix				
							Const	d_{bh}	i_{ba_p}/d_{bh}	h/d_{bh}
	a_0	0.4694	0.544	0.74	3.89E-01	**Const**	1	-0.69	-0.7	-0.97
d_{bh}	a_1	0.1123	0.009	154.81	1.541E-35	**d_{bh}**		1	0.37	0.56
i_{ba_p}/d_{bh}	a_2	3.7130	0.377	97.01	6.889E-23	**i_{ba_p}/d_{bh}**			1	0.6
h/d_{bh}	a_3	-2.5575	0.364	49.32	2.174E-12	**h/d_{bh}**				1

Where: d_{bh}=tree diameter at breast height in cm; h=tree height in m; i_{ba_p}=periodic mean annual tree basal area increment in previous inventory period [cm^2]; Const=constant; SE=standard error; Sign=significance value.
Source: author's own based on SCHRÖDER et al. (2007)

Comparison of S*CHRÖDER*$^{7OR}_{NTM}$ *and* S*CHRÖDER*$^{7ReP}_{NTM}$ *models*. The predictive capacity to estimate mortality of pine trees in Lithuania of these two models was evaluated by applying logistic regression analysis. The following characteristics were checked: Pearson's chi square statistics, log likelihood function value, Cox-Snell and Nagelkerkle's coefficient of determination, ROC area under the curve and percentage of correct classification of growing (1) and dead (0) trees. The basis for evaluation were the 18 Lithuanian PEPs. The statistical results are presented in Table 4-26.

Higher chi-square statistics values show the better correspondence of measured and modelled values. The chi-square value for *SCHRÖDER*$^{7ReP}_{NTM}$ was 1466 and for *SCHRÖDER*$^{7OR}_{NTM}$ was 1044.

By contrast, a lower log likelihood function value shows the better fit of measured and modelled values. The likelihood function value for *SCHRÖDER*$^{7RP}_{NTM}$ was 2127.00 and for *SCHRÖDER*$^{7OR}_{NTM}$ was 2548.18.

The higher values of Cox-Snell and Nagelkerkle's coefficient of determination also show the better correspondence of measured and modelled values. These values were higher for *SCHRÖDER*$^{7ReP}_{NTM}$ than *SCHRÖDER*$^{7OR}_{NTM}$ by 0.11 (Cox-Snell) and 0.14 (Nagelkerkle).

The percentage of correct classifications of growing and dead trees is a very important statistical parameter used to characterise the models (see Table 4-26). *SCHRÖDER*$^{7OR}_{NTM}$ provided 77.47% correct classifications for growing and 76.69% for dead trees, which equates to 77.08% total correct classifications. *SCHRÖDER*$^{7RP}_{NTM}$ provided 82.30% correct classifications for growing and 84.07% for dead trees, which equates to 83.18% total correct classifications. *SCHRÖDER*$^{7RP}_{NTM}$ increased total correct classification by 6.1%.

Table 4-26: Statistical parameters of *SCHRÖDER*^{7OR} and *SCHRÖDER*^{7ReP} logistic models.

Model	Chi-square	Sign	-2 Log likelihood	Cox and Snell R^2	Nagelkerke R^2	ROC Area	Percentage correct		
							1	0	Total
SCHRÖDER$^{7OR}_{NTM}$	1045	0.00	2548.18	0.33	0.44	8.48	77.47	76.69	77.08
SCHRÖDER$^{7ReP}_{NTM}$	1466	0.00	2127.00	0.43	0.58	9.01	82.30	84.07	83.18

Where: Sign=significance.
Source: author's own based on SCHRÖDER et al. (2007).

The last evaluated parameter were ROC curves and the area under them. Figure 4-50a visualises the ROC (blue line) curves for *SCHRÖDER*$^{7OR}_{NTM}$ and Figure 4-50b shows the ROC curves for *SCHRÖDER*$^{7ReP}_{NTM}$. The supplementary Table 4-26 indicates the ROC area for *SCHRÖDER*$^{7OR}_{NTM}$ was 0.848 and for *SCHRÖDER*$^{7ReP}_{NTM}$ was 0.901. HOSMER & LEMESHOW (2000) state that a ROC area higher than 0.8 shows excellent classification.

According to Figure 4-50, with increasing 1- Specificity values, Sensitivity values increase exponentially. The curve of *SCHRÖDER*$^{7ReP}_{NTM}$ increases faster than *SCHRÖDER*$^{7OR}_{NTM}$ and shows better classification. The faster rate of increase of the curve reflects the tendency of the predicted probability values for growing trees to be more concentrated to the right and for dead trees to the left of the prediction interval of 0 to 1. The function y=x is the source of the green line; any model with a ROC curve following the path of this line has no ability to classify dead or growing trees.

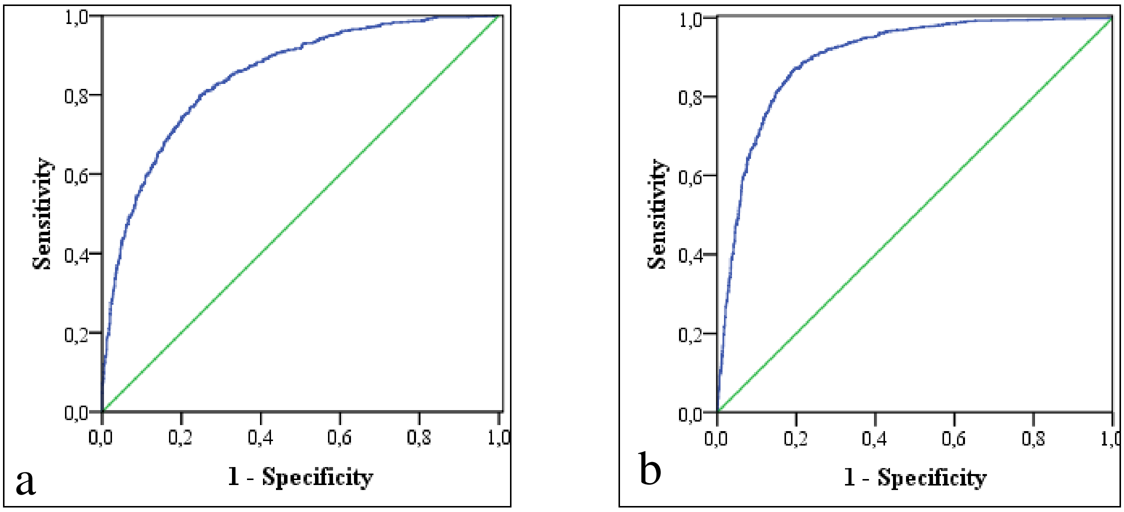

Figure 4-50: Visualisation of ROC curves for (a) *SCHRÖDER*$^{7OR}_{NTM}$ and (b) *SCHRÖDER*$^{7ReP}_{NTM}$ logistic models. The blue line is a ROC curve, the green line is y=x curve (Indicates no discrimination).

To conclude, results of the statistical analysis show that *SCHRÖDER*$^{7ReP}_{NTM}$ increased *SCHRÖDER*$^{7OR}_{NTM}$'s ability to predict NTM of pine trees in Lithuania. This conclusion is supported by all statistical characteristics used in the analysis.

4.4.5.3 Mortality likelihood functions

Mortality likelihood (ML) functions transform F values into likelihood values reproducing mortality as observed in the field for particular F intervals (SCHRÖDER et al. 2007). Firstly, mortality likelihood functions (see Equation 3-47) were estimated for two (F_1 and F_2) mortality logistic models developed by this study. Also, mortality likelihood functions were estimated for SCHRÖDER et al. (2007) original (*SCHRÖDER*$^{7OR}_{ML}$) and re-parameterised (*SCHRÖDER*$^{7ReP}_{ML}$) mortality logistic functions. Table 4-27 shows the main parameter estimates for these models.

The goodness of fit of mortality likelihood function was estimated by using the coefficient of determination R^2. The highest R^2 value (0.996) was found for *SCHRÖDER*$^{7ReP}_{ML}$. In contrast, the lowest R^2 value (0.925) was estimated for *SCHRÖDER*$^{7OR}_{ML}$ with mortality likelihood parameters estimated for Saxony. The estimated R^2 for F_1 was 0.988 and for F_2 was 0.994.

Table 4-27: Parameter estimates for mortality likelihood functions.

Model	R^2	Parameters	Estimate	Std Error
Models, developed by this study				
		a_0	95.8579	0.226
F_1	0.988	a_1	2.7036	0.022
		a_2	1.9276	0.017
		a_0	98.6058	0.140
F_2	0.994	a_1	2.6822	0.011
		a_2	1.7229	0.008
SCHRÖDER et al. 2007 models				
		a_0	100	0.636
$SCHRÖDER^{7OR}_{NTM}$	0.925	a_1	2.6711	0.029
		a_2	1.4626	0.022
		a_0	100.2152	0.132
$SCHRÖDER^{7ReP}_{NTM}$	0.996	a_1	2.6909	0.009
		a_2	1.6433	0.006

Where: F_1 and F_2=natural mortality models developed by this study; R^2=coefficient of determination; Std Error=standard error.

Additionally, to detect the possible deviations, F_1 and F_2 mortality likelihood models were visualised in Figure 4-51, a) and b). According to this figure, these models well represent mortality rates recorded in the field (black squares) with no positive or negative deviations.

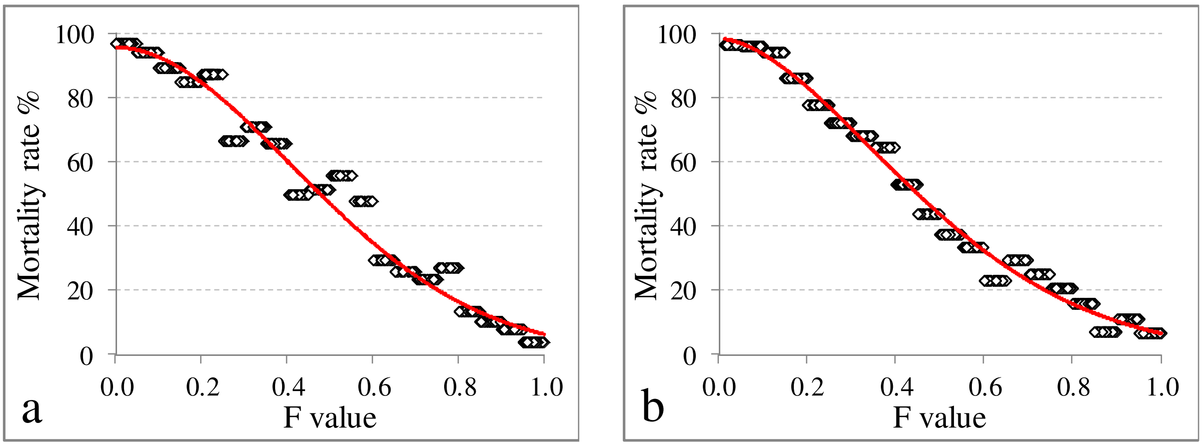

Figure 4-51: Mortality likelihood functions of (a) F_1 model (b) F_2 model.

Figure 4-52a and Figure 4-52b visualise the mortality likelihood models $SCHRÖDER^{7OR}_{ML}$ and $SCHRÖDER^{7ReP}_{ML}$. Figure 4-52a indicates that $SCHRÖDER^{7OR}_{ML}$ tends to overestimate mortality rates in F intervals 0<F<0.3, but in F intervals 0.5<F<1, the model tends to underestimate mortality rates. In contrast, (Figure 4-52, b) $SCHRÖDER^{7ReP}_{ML}$ was very precise.

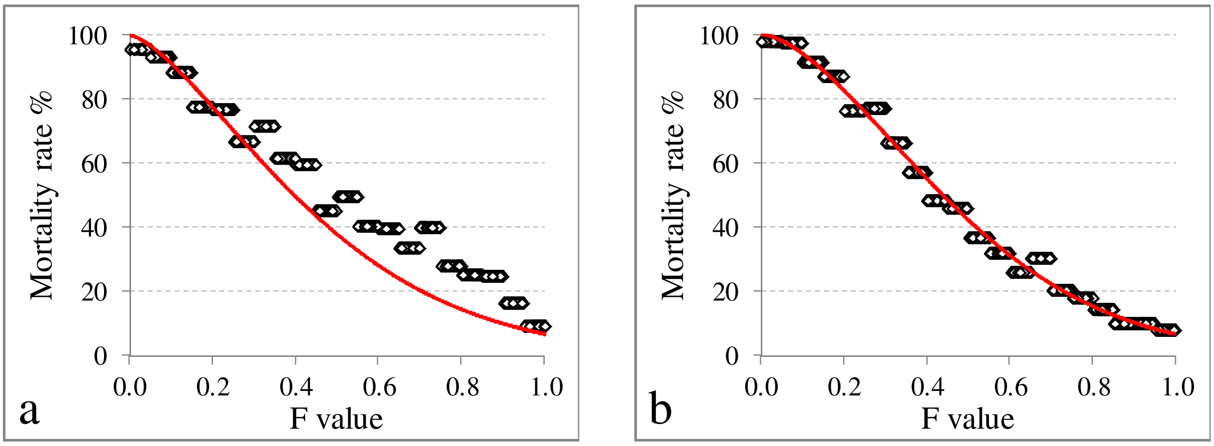

Figure 4-52: Mortality likelihood functions of (a) $SCHRÖDER^{7OR}_{ML}$ and (b) $SCHRÖDER^{7ReP}_{ML}$ models.

To conclude, $SCHRÖDER^{7ReP}_{ML}$ was the most precise, since its coefficient of determination value was the highest and the coefficient of determination values for models F_1 and F_2 mortality likelihood functions were slightly higher than for $SCHRÖDER^{7OR}_{ML}$. Furthermore, the lowest coefficient of determination value was found for $SCHRÖDER^{7OR}_{ML}$. which was the only model that expressed tendencies to underestimate mortality rates.

At the beginning of the study the hypothesis had been formulated that a “Re-parameterised model based on Lithuanian data fits better under Lithuanian conditions regarding mortality”. The re-parameterised natural tree mortality logistic model $SCHRÖDER^{7ReP}_{NTM}$ showed better results than the original $SCHRÖDER^{7OR}_{ML}$ according to all the statistical parameters and provided higher total correct classification by 6.1%. The re-parameterised mortality likelihood function $SCHRÖDER^{7ReP}_{ML}$ showed higher precision than $SCHRÖDER^{7OR}_{ML}$. that had been originally developed for Saxony. $SCHRÖDER^{7OR}_{ML}$ showed tendencies to underestimate mortality rates for Lithuanian growth conditions. On the basis of the provided results it is possible to state that the formulated hypothesis has been confirmed.

4.5 Validation of re-parameterised basal area and height increment models

Re-parameterised basal area increment $\textit{SCHRÖDER}^{7ReP}i_{ba5}$ and height increment $\textit{SCHRÖDER}^{7ReP}i_{h5}$ models need to be validated on the independent data set. The results of validation will show if developed models can reliably predict the growth of trees in practice. For this purpose, the re-parameterised basal area and height increment models were entered into the BWINPro-S simulator.

4.5.1 Description of validation plots

The study used two validation plots (VP), VP5 and VP7. Detailed descriptions of plots are presented in Table 4-28 and Appendix 2. Both plots were established in 1983, and in the intervening period VP5 was re-measured four times and VP7, two times. The last inventories occurred in 2008 (VP5) and 2012 (VP7). The MSA at the first and last inventories of the VPs were 34 years and 59 years for VP5 and 60 years and 89 years for VP7. VP5 is a single-layered stand and VP7 is a double-layered stand. Two tree species (pine and spruce) were recorded in VP5, and three species (pine, spruce and birch) in VP7. Since models have been developed only for pine, other tree species are left aside from further analysis.

Table 4-28 shows that from the first to the last inventories, VP5's site indices H_{AB} and D_{AB} had increased from 25.3 to 28.4m, and 28.9-30.8cm, respectively. Likewise, during the same inventory period, VP7's site indices H_{AB} and D_{AB} had increased from 28.5 to 29.0m and from 31.2 to 32.8cm. The site productivity index H_{AB} indicates VP5 and VP7 appear in the higher potential productivity group, while the D_{AB} site index indicates VP5 and VP7 appear in the potentially fertile 30cm productivity group, or one group lower.

In the 25 year inventory period, H_{100} in VP5 increased from 15.0 to 24.3m and in the 29 year inventory period for VP7 increased from 24.7 to 30.0m. Similarly in their distinct inventory periods, D_{100} in VP5 increased from 18.5 to 29.9cm and in VP7 increased from 30.5 to 40.2cm. H_q in VP5 increased from 12.8 to 22.1m and in VP7 increased from 22.4 to 27.8m. The D_q in VP5 increased from 12.2 to 21.6cm and in VP7 increased from 22.2 to 30.7cm. The number of pine trees in VP5, from 1983 to 2009, decreased from 2064 to 980 trees ha^{-1}, and in VP7, from 2003 to 2012 pines decreased from 588 to 435 trees ha^{-1}. In the same distinct inventory periods, the standing volume (V) of pine trees in VP5 increased from 161.4 to 378.3 m^3 ha^{-1} and in VP7, V increased from 243.6 to 415.5 m^3 ha^{-1}; gross yield (GY) in VP5 increased from 161.4 to 469.7 m^3 ha^{-1} and in VP7 from 243.6 to 459.1 m^3 ha^{-1}.

Table 4-28: Results of standard analysis of Validation Plots 5 and 7.

inv	MSA	Species	N trees ha^{-1}	H_{AB} m	D_{AB} m	H_{100} m	D_{100} cm	H_q m	D_q cm	V m^3 ha^{-1}	$N_{removed}$ trees ha^{-1}	$V_{removed}$ m^3 ha^{-1}	GY m^3 ha^{-1}
Validation Plot 5													
1983	34	Pine	2064	25.3	28.9	15.0	18.5	12.8	12.2	161.4	0	0	161.4
		Spruce	32			15.2	12.5	15.2	12.5	3.4	0	0	
2008	59	Pine	980	28.4	30.8	24.3	29.9	22.1	21.6	378.3	480	44.8	469.7
		Spruce	20					23.9	20.1	8.1	0	0	
Validation Plot 7													
1983	60	Pine	588	28.5	31.2	24.7	30.5	22.4	22.2	243.6	0	0	243.6
		Birch	55					21.0	19.2	15.6	0	0	
		Spruce	223					18.3	16.4	46.1	0	0	
2012	89	Pine	435	29.0	32.8	30.0	40.2	27.8	30.7	415.5	153	43.6	459.1
		Birch	33					23.4	24.9	16.7	23	4.4	
		Spruce	195					21.4	22.5	84.4	203	4.2	

Where: inv=the year of inventory; MSA=mean stand age in years; N=the number of growing trees ha^{-1}; H_{AB}=site productivity index according to the mean stand height at base age (100 years) in m; D_{AB}=site productivity index according to the stand mean diameter at base age (100 years) in cm; H_{100}=mean height of 100 largest trees per ha or stand top height in m; D_{100}=mean diameter of 100 largest trees per ha or stand top diameter in cm; V=standing volume [m^3 ha^{-1}]; $N_{removed}$=the number of self-thinned trees ha^{-1}; $V_{removed}$=volume of removed stand [m^3 ha^{-1}]; GY=gross volume yield [m^3 ha^{-1}].

To conclude, the selected validation plots well represent higher potential productivity group stands according to site productivity index H_{AB}. They are potentially fertile, with average diameter growth conditions, according to site productivity index D_{AB}. The growth dynamics of trees on the validation plots did not vary remarkably from the growth dynamics of trees on the PEPs. Thus, the selected plots are appropriate for validation of the developed models.

4.5.2 Validation of re-parameterised BWINPro-S basal area increment model

Validation of $\mathit{SCHRÖDER}^{7ReP}i_{ba5}$ was achieved by simulating basal area increment and then transforming it to tree diameters at breast height (d_{bh}). In this way, the capacity of modelling of tree diameter increments is estimated indirectly. In order to validate the model, these two graphical measures are used: 1) comparison of d_{bh} values measured in the field and modelled after the simulation period and 2) homogeneity of variance of prediction residuals. To visualise if model residuals were equally distributed in all range of predicted d_{bh} values, Loess nonparametric regression was applied. To reveal the precision of predictions, these statistical parameters are used: bias, relative bias, precision, relative precision, accuracy and relative accuracy.

Figure 4-53 presents the comparison of measured (2008) and modelled (post-1983-2008 simulation period) d_{bh} values in VP5, produced by the $\mathit{SCHRÖDER}^{7ReP}i_{ba5}$ model.

The red line in this figure is the trend line from the data with an intercept equal to 0 and the blue line is a function y=x with supressed intercept. Models tend to be very precise if the blue and red line match. Figure 4-53 indicates that predictions of $\mathit{SCHRÖDER}^{7ReP}i_{ba5}$ model in VP5 have a negative bias. The slope coefficient of the red trend line is equal to 0.89. However, the coefficient of determination between the measured and modelled d_{bh} values with suppressed intercept was comparably high (0.48).

Figure 4-54 presents the homogeneity of variance of prediction residuals, which in combination with the nonparametric Loess regression red line indicates that the *SCHRÖDER*^{7ReP}i_{ba5} model underestimates d_{bh} values in all ranges up to 3.41cm.

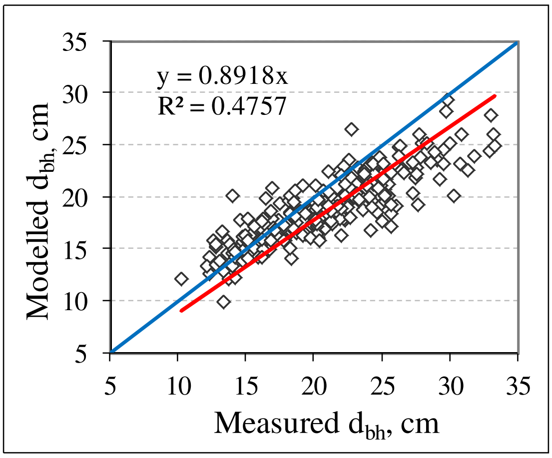

Figure 4-53: Comparison of measured (2008) and modelled (1983-2008) diameter at breast height (d_{bh}) values in Validation Plot 5, produced by *SCHRÖDER*^{7ReP}i_{ba5} model.

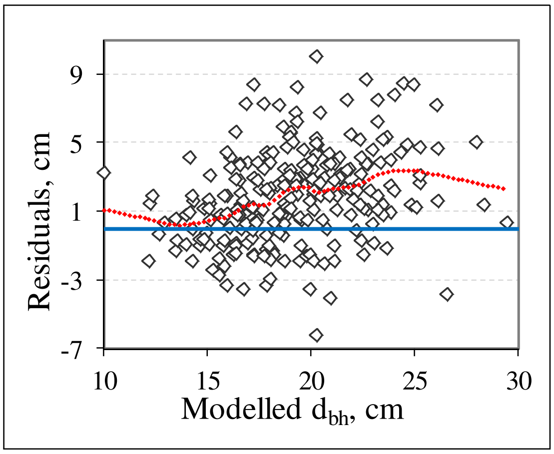

Figure 4-54: Homogeneity of the variance of prediction residuals in Validation Plot 5, produced by *SCHRÖDER*^{7ReP}i_{ba5} model.

The same validation procedures were carried out for VP7. The growth of trees in this plot was simulated from 1983 to 2012. Figure 4-55 presents the comparison of measured (2012) and modelled (post-1983-2012 simulation period) d_{bh} values in VP7, produced by the *SCHRÖDER*^{7ReP}i_{ba5} model. The comparison found a very small negative bias. The slope coefficient of the trend line with suppressed intercept was 0.989 and the coefficient of determination was 0.89.

Figure 4-56 visualises the homogeneity of variance of prediction residuals for VP7, which in combination with the nonparametric Loess regression red line, indicates that the *SCHRÖDER*^{7ReP}i_{ba5} model in the interval of 16.6-23.2cm tends to underestimate d_{bh} values by up to -1.07 centimetres. The *SCHRÖDER*^{7ReP}i_{ba5} model in the interval of 23.2-30.4cm overestimates d_{bh} values by up to 0.7cm; in the interval of 30.4-39.0cm estimates d_{bh} values precisely and in the interval 39.0-53.5cm overestimates d_{bh} values by 1.6 centimetres. Despite these minor deviations, the results of *SCHRÖDER*^{7ReP}i_{ba5} model are generally very good in VP7.

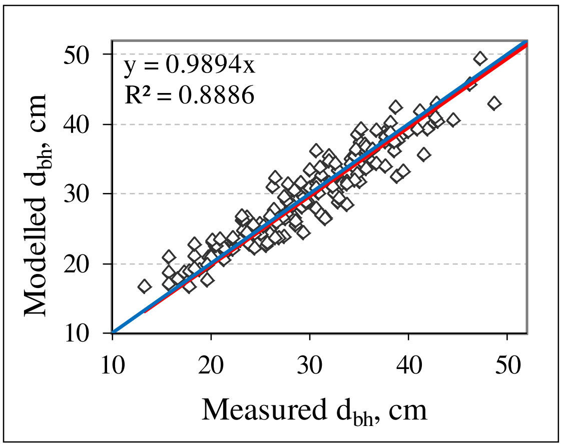

Figure 4-55: Comparison of measured (2012) and modelled (1983-2012) diameter at breast height (d_{bh}) values in Validation Plot 7, produced by *SCHRÖDER*^{7ReP}*i_{ba5}* model.

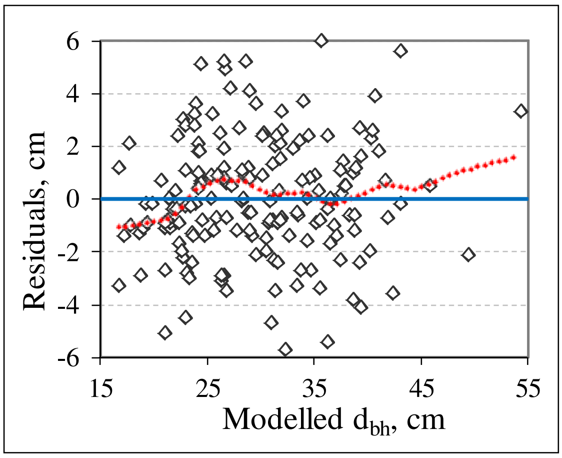

Figure 4-56: Homogeneity of the variance of prediction residuals in Validation Plot 7, produced by *SCHRÖDER*^{7ReP}*i_{ba5}* model.

Table 4-29 presents the results of statistical validation of *SCHRÖDER*^{7ReP}*i_{ba5}* model in VP5 and VP7. In both VPs, the coefficient of determination (R^2) between measured and modelled d_{bh} values was very high - 0.71 for VP5 and 0.896 for VP7. However, a remarkably strong bias of -10.04% was observed in VP5.

Appropriately, both the precision and accuracy of *SCHRÖDER*^{7ReP}*i_{ba5}* were comparably low. Precision was 12.94% and accuracy 15.84% in VP5. Much better results were observed in VP7, where the bias was only -0.35%, precision was 7.93% and the accuracy was 7.94%.

Table 4-29: Validation results of *SCHRÖDER*^{7ReP}*i_{ba5}* model in validation plots 5 and 7.

Plots	R^2	STE	BIAS	BIAS %	PREC	PREC %	ACCUR	ACCUR %
5	0.71	1.763	-1.920	-10.04	2.722	12.94	3.334	15.84
7	0.896	2.185	-0.103	-0.35	2.363	7.93	2.365	7.94

Where: R^2=coefficient of determination; STE=standard error; PREC=precision; ACCUR=accuracy.
Source: author's own based on SCHRÖDER et al. (2007).

To conclude, *SCHRÖDER*^{7ReP}*i_{ba5}* model produced remarkable negative bias in VP5, when growth of trees was modelled from 34 to 59 years. Despite this, *SCHRÖDER*^{7ReP}*i_{ba5}* model was very precise in VP7 when growth of trees was simulated from 60 to 89 years.

4.5.3 Validation of re-parameterised BWINPro-S height increment model

Validation of $\textit{SCHRÖDER}^{4Rep}i_{h5}$ model was achieved by performing the same analysis as done in the previous subsection. Firstly, tree height increments were modelled and then measured and modelled tree heights at the end of the simulation period were compared.

Figure 4-57 visualises the comparison of trees' height values measured in 2008 and modelled after the post-inventory 1983-2008 period in VP5. The prediction capacity of $\textit{SCHRÖDER}^{4Rep}i_{h5}$ had a small negative bias. The slope coefficient of the red trend line with a supressed intercept was 0.956. Coefficient of determination R^2 between measured and modelled height values with suppressed intercept was 0.063.

Figure 4-58 visualises the homogeneity of the variance of the prediction residuals, which in combination with the nonparametric Loess regression red line, $\textit{SCHRÖDER}^{4Rep}i_{h5}$ in the interval from 13.6 to 22.4m tends to overestimate modelled height values by up to 3.8m and in the interval from 22.4 to 27.4m tends to underestimate modelled height values by up to -1.8m.

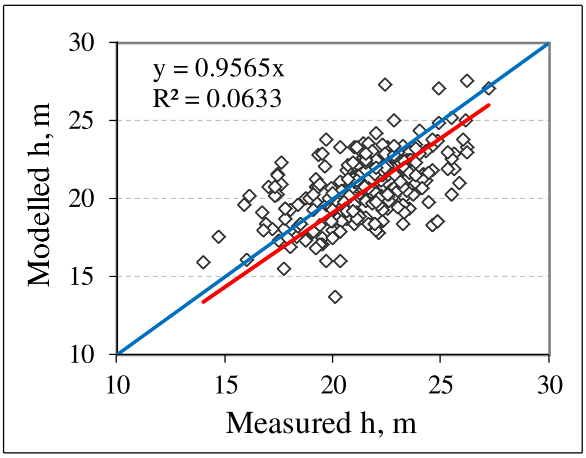

Figure 4-57: Comparison of measured (2008) and modelled (1983-2008) tree height (h) values in Validation Plot 5, produced by $\textit{SCHRÖDER}^{4Rep}i_{h5}$ model.

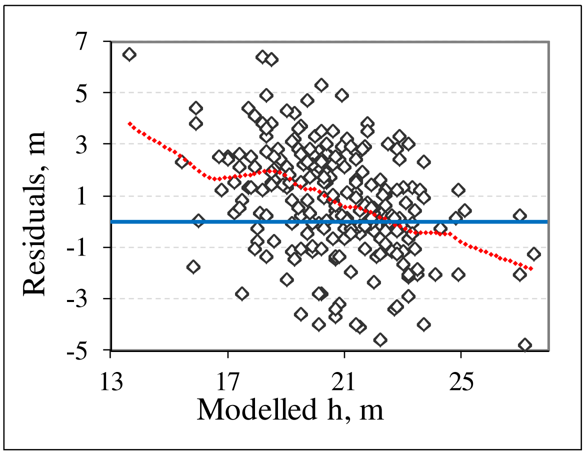

Figure 4-58: Homogeneity of the variance of prediction residuals in Validation Plot 5, produced by $\textit{SCHRÖDER}^{4Rep}i_{h5}$ model.

Figure 4-59 presents the comparison of trees' height values measured in 2012 and modelled after the post-inventory 1983-2012 inventory period in VP7. The prediction capacity of $\textit{SCHRÖDER}^{4Rep}i_{h5}$ had a small positive bias. The slope coefficient of the red line with a suppressed intercept was 1.039. The coefficient of determination between measured and modelled height values with suppressed intercept was 0.003.

Figure 4-60 visualises the homogeneity of the variance of prediction residuals. The nonparametric Loess regression line (red) indicates that the $\textit{SCHRÖDER}^{4Rep}i_{h5}$ in the interval from 20.8 to 23.5m tends to overestimate height values by up to 2.1m and in the interval from 23.5 to 37.7m tends to underestimate height values by up to -7.2 metres.

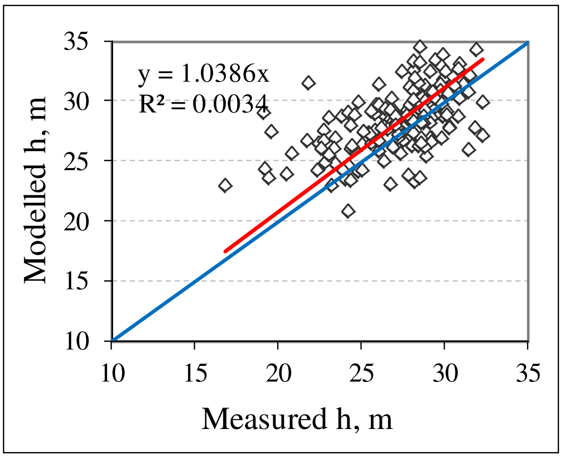

Figure 4-59: Comparison of measured (2012) and modelled (1983-2012) tree height values in Validation Plot 7, produced by *SCHRÖDER*$^{4Rep}i_{h5}$ model.

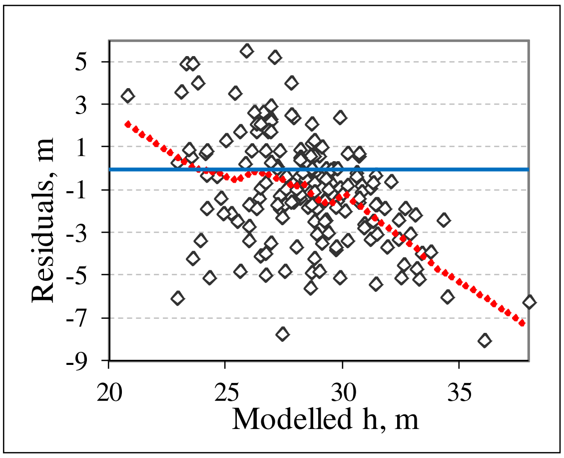

Figure 4-60: Homogeneity of variance of prediction residuals in Validation Plot 7, produced by *SCHRÖDER*$^{4Rep}i_{h5}$ model.

Table 4-30 presents the results of statistical validation of *SCHRÖDER*$^{4Rep}i_{h5}$ in VP5 and VP7. In both VPs the coefficient of determination (R^2) between measured and modelled tree height values was comparably low at 0.301 for VP5 and 0.304 for VP7. *SCHRÖDER*$^{4Rep}i_{h5}$ produced a negative bias of -3.97% in VP5, but in contrast produced a positive bias of 4.25% in VP7. The precision of *SCHRÖDER*$^{4Rep}i_{h5}$ was slightly better in VP7 (9.82%) than in VP5 (9.96%). The accuracy of *SCHRÖDER*$^{4Rep}i_{h5}$ was slightly better in VP5 (10.67%) than in VP7 (10.78%)

Table 4-30: Validation results of *SCHRÖDER*$^{4ReP}i_{h5}$ model in validation plots 5 and 7.

Plot	R^2	STE	BIAS	BIAS %	PREC	PREC %	ACCUR	ACCUR %
5	0.301	1.807	-0.820	-3.97	2.138	9.96	2.291	10.67
7	0.304	2.294	1.208	4.25	2.673	9.82	2.935	10.78

Where: R^2=coefficient of determination; STE=standard error; PREC=precision; ACCUR=accuracy.
Source: author's own based on SCHRÖDER et al. (2007).

To conclude, *SCHRÖDER*$^{4Rep}i_{h5}$ model produced a negative bias in VP5 when growth of trees was modelled from 34 to 59 years. By contrast, the bias was positive in VP7 when growth of trees was simulated from 60 to 89 years. However, these deviations were comparably low.

4.5.4 Validation of stand level parameters

Stand level variables like top diameter (D_{100}), quadratic mean diameter (D_q), top height (H_{100}), mean height (H_q) and standing volume (V) are very informative and easily calculated from tree level variables. Thus, variables measured in 2008 and in 2012 were compared with stand level variables predicted in 1983-2008 and in 1983-2012 (see Table 4-31).

The *SCHRÖDER*$^{7ReP}i_{ba5}$ model remarkably reduced predictions of increments of tree diameter in VP5. As a consequence, D_{100} values derived from model's predictions (1983-2008) were 16.1% lower than D_{100} values derived from the field measurements in 2008. Appropriately, D_q

calculated from model's predictions was reduced by 9.7% from that derived from the field measurements in 2008. The predictions of the *SCHRÖDER*$^{7ReP}i_{ba5}$ model in VP7 were much more precise. The D_{100} value estimated from model's predictions (1983-2012) was only 1.7% lower than the D_{100} value derived from the field measurements in 2012. The values of D_q calculated from model's predictions were 0.7% lower than those derived from the field measurements in 2012.

Table 4-31: Evaluation of *SCHRÖDER*^{4OR} and *SCHRÖDER*^{4ReP} models capability to estimate main stand level variables.

		D_{100} cm	D_q cm	D_{100} cm	D_q cm	H_{100} m	H_q m	H_{100} m	H_q m	V m^3 ha^{-1}	
		Plot 5		Plot 7		Plot 5		Plot 7		Plot 5	Plot 7
From field measurements		29.9	21.6	40.2	30.7	24.1	22.0	30.3	28.0	360.7	411.7
Predicted by model		25.1	19.5	39.5	30.5	22.9	21.0	30.6	28.9	277.7	420.6
Difference	**Absolute**	-4.8	-2.1	-0.7	-0.2	-1.2	-1	0.3	0.9	-83	8.9
	Relative %	-16.1	-9.7	-1.7	-0.7	-5	-4.5	1	3.2	-23.0	2.2

Where: D_{100}=mean diameter of 100 largest trees per ha or stand top diameter in cm; D_q=quadratic mean diameter of remaining stand in cm; H_{100}=mean height of 100 largest trees ha^{-1} or stand top height in m; H_q=mean stand height in m; V=standing volume [m^3 ha^{-1}].

SCHRÖDER$^{4Rep}i_{h5}$ model, in VP5, reduced H_{100} values from the model's predictions (1983-2008) by 5% compared to H_{100} value from the field measurements in 2008. The model also reduced H_q value in VP5 by 4.5%. The *SCHRÖDER*$^{4Rep}i_{h5}$ model did produce very precise predictions in VP7 (see Table 4-31). The H_{100} value from model's predictions (1983-2012) was higher by 1% than the H_{100} value from the field measurements in 2012, and accordingly, the model increased the H_q value by 3.2%.

The predicted standing volume (V) in VP5, at the end of the simulation period was 23% lower than V measured in the field in 2008. The predicted V in VP7, at the end of the simulation period was 2.2% higher than V measured in the field in 2012.

4.6 Concluding remarks

The last hypothesis in this study was that a "Single Tree Level Simulator would provide a valuable support for decision makers and forest managers to improve forest management in Lithuania". The benefits of each model would lie in the aspect of STLS's ability to present reliable results.

The statistical analysis of all re-parameterised (^{ReP}) models: basal area increment (i_{ba}), height increment (i_h) and natural tree mortality (NTM) of this study proved the reliability of STLS. The comparison of BWINPro-S simulated growth of trees with the measured growth in the field of the two validation plots produced satisfactory results. On the basis of these findings the formulated hypothesis is accepted.

5 DISCUSSION

5.1 New forest management tools in Lithuania

Forest management in Europe in the last two centuries has shifted from maximum timber production and maximum economic outcome to sustainable forest management when society, economics and the environment became equally important. However, the productivity of commercial forest stands remains one of the central goals of traditional forest silviculture. There are many factors affecting forest growth and yield, such as climatic conditions, genetic material, potential site productivity, tree age, stand structure and silvicultural treatments (ASSMANN 1970 and PRETSCH 2009). The variety of influencing factors makes forest management a complex issue.

Melding the data of lengthy scientific investigations with digital technologies has enabled the development of many computer aided tools, particularly models and simulators, to facilitate forest management.

The development process of modelling, moving from macro to micro scales began initially with the macro of whole stand models (yield tables), followed by size class models and recently has focused on ecophysiological processes, hybrid simulators and single tree level (micro scale) simulators (see subsection 2.4.1).

Scientific research in Lithuania on developing stand level models has increased since the 1960s, for example, summarised forest yield models for pure even-aged stands (KULIEŠIS 1993). Lithuania had not prior to the beginning of the second decade of the 21st century developed any single tree level growth models, for reasons explained below, despite of the advanced capabilities of digital technologies and the need for micro-scale modelling.

Lithuania's climate – northern European continental – allows the growth of both conifers and broadleaved species, both of which should be the focus of forestry research. Despite the capabilities of both digital technologies and modelling programmers, stand level growth models perform poorly in the context of mixed stands (see PRETSCH 2009). Concomitant to this performance failure, forest management in Lithuania have not either developed a local single tree level growth model nor applied forest growth simulators. The construction and development of a single tree level simulator (STLS) could fill this research gap.

Although the adequate scientific knowledge and computer skills required for the development of an STLS tool are available in Lithuania, the process for small countries may not be cost effective. An easier, quicker and less costly solution is to use and adapt the experience of other countries with similar climatic and growth conditions that have already developed the required scientific tools. Lithuanian forest scientists and management have in recent decades turned to, and adapted, the expertise of German forestry scientists. Therefore, this study focused on the BWINPro-S simulator that was developed for the Saxony and is used in forest management practice (RÖHLE et al. 2004).

The overall objective for this study was to re-parameterise and introduce a STLS for Lithuanian pine forests, growing on mineral sites. Due to the peculiarities of local growth conditions, new pine growth models were also constructed.

Even though the BWINPro-S simulator is used mainly in mixed stands, the focus of this study did not allow testing on all tree species. Another factor that limited the scope of the study was that the only data available concerned PEPs of pure pine. However, the components of growth models are calculated for each species separately. Thus, on the basis of this study, it will be easy to introduce other tree species into the growth simulator. Finally, adaptation of this simulator for growth modelling of mixed stands would provide additional benefits for Lithuanian forest management.

5.2 Evaluation of complete database used for modelling

5.2.1 Sample size and data representativeness

Reliable modelling of forest growth requires representative and high quality data. This study used a unique dataset consisting data from 16 (permanent experimental plots) PEPs established in 1983-1985 period and 2 PEPS established in 1990 and 1992. The aim of establishing these PEPs was to investigate the productivity of pine stands, and were as a result located in the central and southern pine productivity regions, III and IV (see Figure 3-6).

Although the necessary field measurements were available to the study, the dataset provided crucial modelling-related data, such as the main parameters of trees - d_{bh}, h and h_{cb} - the coordinates of each tree.

The ages of the stands in the PEPs ranged from 7 to 75 years, and consequently after 30 years of observation this age range was comparable to commercial stands. Similarly, the stands in the PEPs were representative of the most common Lithuanian conditions for height growth (H_{AB} - 19-33m) and tree diameter growth (D_{AB} - 21-42m), which comprise the most important productivity regions for pine in Lithuania (Figure 3-6; Regions III and IV).Thus, the sample used to develop and re-parameterise the models was representative of Lithuanian pine forests.

The scarcity of permanent sample plots available for study is partly due to forest research practices and partly due to forest management practices. Whereas temporary research plots for tree growth analysis is a common Lithuanian forest research practice, long-term experimental plots (PEPs) that have been inventoried every five years are not a common practice and those that do exist comprise a scarce resource. Those that do exist, due to the focus of Lithuania's forest management being on maximally productive pure pine or pure spruce stands, rarely consist of mixed stands. Furthermore, many of the PEPs that were established prior to the restitution of independence in 1991 have not been re-inventoried since and are thus unsuitable for modelling purposes. Yet, they are appropriate for validating a model.

JOHNSON (2000) indicates that sampling in forestry should be done in a random manner, with a constant probability of selection, or systematic manner when elements of the sample are selected from the frame at some specified interval. However, despite the need to adhere to rules when selecting the PEPs, it was necessary to select fully stocked, un-thinned stands covering 10-100 years age and site productivity range of H_{AB} from 20 to 32 metres intervals. Since the highest share of pine trees grow in fourth productivity region (see Figure 3-6) most of the PEPs also were located in this productivity region.

As a result of estimates of the population's mean values was the selected sample size proven representative of Lithuanian tree populations of the local regions III and IV. The only mean value that exceeded the predefined accuracy concerning standard deviation was crown width.

The size of the database used in this study is smaller than databases used to develop other STLSs. For example, PRETZSCH et al. (2002) state that for development of the SILVA simulator, data was collected in 288 permanent sample plots on 570 occasions, producing 155000 tree observations. RÖHLE (1999) in developing BWINPro-S growth models, used the ORACLE database that consisted of data from 252 long-term trial areas distributed throughout Saxony with a total of 240000 tree observations. MONSERUD & STERBA (1996) in developing the distance independent simulator PROGNAUS used Austrian National Forest Inventory data.

There were two further limitations on the quantity of available data. First, the significant disparity of growth conditions for pine trees between the maritime climate of the west and the continentallity of the south meant that there was no data for the western part of Region III and the whole of Region I (see subsection 3.1). Second, there were no viable PEPs in the north (Region II).

5.2.2 The potential site productivity and forest yield

Prior to analysing site productivity and forest yield, the hypothesis was formulated that "Site quality is the most important factor that affects forest growth and yield".

KAIRIŪKŠTIS & JUODVALKIS (1985) found that the most important factors for forest growth and yield are density of trees in the stand, the proportion of the most productive trees and the level of homogeneity in distribution. The results of the current study (Table 4-1, Figure 4-8) show that forest growth and yield depends not only on the potential productivity of sites according to H_{AB} or D_{AB}, but also on forest formation type.

The influence of forest formation type is important because it means that stands growing on more fertile sites could be less productive than stands growing on less fertile sites. Forest formation type depends on the peculiarities of natural tree mortality (NMT) in the stands that could be defined by the dynamics of the following variables: stand level competition index (CI_{Stand}), stocking level, d_{bh} and h ratio, number of growing trees ha^{-1}, and the volume of self-thinned trees (KULIEŠIS 1989a).

Well-timed thinning of trees at $Y^{1\text{-}40}$age guarantees quite intensive on-going growth, ability to maintain normal stocking levels and develop resistance to negative growth factors like storms, droughts or beetle infestation. Thinning also ensures the capabilities for intensive growth and accumulation of volume increments up to $Mat^{101\text{-}140}$age and maximal standing volumes. These characteristics are very typical for normal forest formation type stands. By contrast, stands that are very dense, where there is very high competition for growing space (accelerated forest formation type) quickly accumulates high standing volumes, but then loses growth energy and resistance to negative growth factors. Consequently, the self-thinning during later growth stages can be very intensive. As a result, stand yields and accumulated volumes for final felling decrease and the trees cannot exploit the growth potential provided by site conditions. Furthermore, low rates of self-thinning at $Y^{1\text{-}40}$age causes a decrease in the growth rate of trees. In very dense stands trees form the crown dimensions typical for low productivity trees (compressed crowns, see OZOLINČIUS 1996). KAIRIŪKŠTIS & JUODVALKIS (1985) supports these findings by stating that during formation period at $Y^{1\text{-}40}$age trees do not suffer from negative interactions due to high densities. Too high density of stands at $Y^{1\text{-}40}$age is the main reason for growth stagnation or even degradation in the later growth stages.

These statements are well illustrated by the results of this study. For example, PEPs 82 and 83 have the same site productivity index (H_{AB}=31m, at the age of 60 years). The standing volume (V) in PEP 82 is less than 200 m^3 ha^{-1}, whereas V in PEP 83 is around 400 m^3 ha^{-1}. Furthermore, the growth and yield of stands are greater with H_{AB}=28m than with H_{AB}=31m (Table 4-1, Figure 4-8).

Stands growing on more productive sites are more vulnerable to overcrowding effects than those growing on poorer sites. Due to faster growth, they are more intensively self-thinned than those growing on less productive sites.

The results of German research show that light thinning at Y^{1-40}age can increase stand productivity (see for example ASSMANN 1970, PRETZSCH 2009). By contrast, results of Scandinavian research show that thinning only decreases stand productivity (see for example SKOVSGAARD 2009, NILSSON et al. 2010). Thus, this research question requires additional attention. These contrasting results could be observed due to different climatic conditions and growth limiting factors like temperature, solar radiation and precipitation. Even more, the differences in site productivity could play an important role as well.

These findings are very important for practical forestry, because they clarify the main principles of forest productivity. Well-timed thinning, especially the first pre-commercial instance, leads to higher productivity of stands. By contrast, absence of pre-commercial thinning or late pre-commercial thinning could be the reason for lower yields, especially on more productive sites.

The major weakness of this study concerning forest productivity was the brevity of the observation period of the PEPs. Observations of the majority of the plots started after the initial stress effect described by KAIRIŪKSTIS & JUODVALKIS (1975) and the closure of the crowns had appeared among the trees growing in the PEPs. Thus, in the current study most of the conclusions were accepted by consolidating the results from the various PEPs growing on different sites and at different ages. Therefore, the development of the stands can be different from the expected. These shortcomings have to be kept in mind when interpreting the results.

To summarise the discussion on site productivity and forest yield, well-timed regulation of competition for growing space is the key factor to achieve the optimal balance between the largest possible growth of trees and the highest accumulated volumes in the stand. Productivity of pure stands in Lithuania already has been analysed in detail for more than 50 years. Further research should focus on productivity analysis of mixed forest stands.

5.3 Analysis of competition for growing space

The first attempts to analyse the competition indices (CIs) in Lithuania were the works of JUKNYS (1990) and (OZOLINČIUS 1996). However, these studies focused more on revealing the fundamental growth peculiarities of conifer trees without any claims to develop tree growth models in Lithuania. Thus, the current study of CIs is possibly the first work of this type in Lithuania. It covers analysis of various distance dependent and independent CIs with special attention to their tree growth predictive capacities.

The partial impact of competition on the periodic mean annual basal area increment: It was hypothesised that "distance dependent competition indices yield higher partial correlation coefficients with tree basal area increment than distance independent competition indices". This hypothesis was driven by the assumption that the inclusion of tree positions increase the predictive capacity of CIs. The results clearly show the dominance of distance dependent indices over distance independent indices to predict the periodic mean basal area increment. The mean partial correlation coefficient of the best distance dependent index was 2.5 times higher than the best distance independent index and the proportion of significant cases of the best distance dependent index was 2.7 times higher than the best distance independent index. Yet, the difference between the poorest distance dependent and the best distance independent index was hardly noticeable. This reveals two very important findings. First, distance independent indices are also appropriate for modelling the growth of pure stands. Second, the predictive values of distance dependent indices are highly dependent on the selection method and the CI used.

The selection method HCB 80 seems to be the most suitable for Lithuanian conditions. This method creates an average size of search cone because its positioning height increases over time, with the increasing height to crown base. The selection method HWCW 60 creates the shortest size of search cone that does not significantly increase in length over time. Particularly in older stands, this method probably does not include some important competitors and leads to index values that are too low. Selection method SB 60 creates the longest search cone that identifies the highest number of competitors. This leads to the risk that it includes trees that have no influence on the subject tree and thus increases the value of CI to an implausible level.

Since the 1950s, many CI formulae have been developed and they have become increasingly advanced. However, this progress also has a negative side in that more and more information describing tree properties is needed. Early CI formulae only required data on tree diameter at breast height. Today most indices require all tree crown parameters, as well as stem coordinates, and despite this, the results of index-based increment estimation have improved only slightly. It is very expensive to gather this type of data in practice, so models to simulate the data required have been developed.

LORIMER (1983), MARTIN & EK (1984), DANIELS et al. (1986), CORONA & FERRARA (1989), BIGING & DOBBERTIN (1995) show that distance independent CIs in pure stands performed as well as distance dependent CIs, and in some cases showed better results. An explanation could be that most of these authors compared indices that were not based on crown parameters. When comparing distance dependent and distance independent indices, only slight improvements were achieved by adding tree coordinates (HEGYI 1974). BIGING & DOBBERTIN (1992), BACHMANN (1998), SCHRÖDER (2004) and others describe the slight advantage of distance dependent indices based on crown variables, especially crown cross sectional area. Their results are clearly in line with our findings.

Based on the partial correlation results (Table 4-6), CI_4 proposed by BIGING & DOBBERTIN (1992) combined with the selection method of an inverse search cone at height to crown base with an opening angle of 80 degrees is recommended for developing basal area increment models used in single tree level growth simulators. However, the difference between the first three places in Table 4-6 was small. Thus, the other indices CI_5 and CI_6 used with the same selection method could be applied for modelling purposes depending on the model constructed.

This study of CIs has relevant practical importance. The best predefined CI will be used in tree diameter growth models. This parameter will modify the diameter increments to particular competitive conditions of trees. So, performance of a selected CI will have a direct impact on the precision of diameter growth models.

Our study has some limitations. The selection of CIs was based on the results of previous studies and not all of the available indices were tested. No distance independent CI based on crown variables was tested. Furthermore, even the best distance dependent CI did not perform outstandingly, but scored only satisfactory results. Finally, CIs were only tested in pure stands and only for one tree species.

Further research should focus, not on the development of new formulae, or on the inclusion of additional tree information, but, rather, on the aggregation of the indices already developed. For example, algorithms to eliminate passive competitors in the formulae might be useful.

The partial impact of competition on the periodic mean annual height increment: The major finding on this issue was that HEGYI'S (1974) distance independent CI scored better partial correlation results than all of the distance dependent indices. Thus, the research hypothesis had to be rejected, contrary to prior expectations. A very important result was that the more competitors were included, the better were the results obtained (Table 4-7). The summary given in Table 4-7 underlines the poor performance of CIs to predict tree height increment and because of this, CIs should not be used in height growth models under conditions similar to this study, i.e. in pure and single-layered stands of a light demanding species like pine.

Contradictory and unusual results were found in the literature while analysing the research question. WYKOFF et al. (1982) developed their height growth model without CIs. The early findings of MARTIN & EK (1984) showed that no significant improvement in the height growth models could be achieved by including CIs. BIGING & DOBBERTIN (1992) contradicted these results by stating that the inclusion of CIs considerably improves height growth predictions. PRETZSCH (2002) applied a CI as a modifier in his height growth model, yet used the crown surface area of trees as well. NAGEL et al. (2002) employed an individual tree height ratio to stand top height rather than a CI to reduce potential height growth.

These results have very important practical relevance. Under the environmental and soil conditions prevalent in Lithuania, CIs did not meet expectations in partial correlation analysis. Thus, they are not recommended as growth modifiers in tree height increment models. Because of this, further research should focus on finding more powerful modifiers in height increment models rather than CIs.

The impact of competition on relative diameter and relative height increment: The results suggested that competition generally has a negative impact on tree diameter growth. Tree diameter increment decreases with increasing competition. A small amount of competition, however, stimulates tree height growth. These findings were in line with our expectations, and set the basis for constructing diameter and height increment models. Logarithmic transformations of CIs make their relation with diameter or basal area increment accessible for linear regression analysis, but this transformation was of little help in the case of tree height increment (when transforming nonlinear function, see Figure 4-20b). This could be one of the reasons for the poor performance of CIs in predicting the height increment of trees.

The results of our study are comparable to Pretzsch's (2009) results: he found that the maximum diameter increment is reached with no competition, and maximum tree height increment takes place under a moderate level of competition. This shows that under light competition, trees allocate their resources to increase height increment.

These findings have significant practical importance. In case of diameter increment maximization all competitors around the subject tree have to be eliminated. If the goal is to maximize the height increment, some competitors around the subject tree have to remain.

The main limitation of our study was that the results are valid only for the CIs and selection methods investigated. The indices with the lowest partial correlation values showed a very weak relationship, or no relation, with relative diameter or height increment.

5.4 Modelling tree growth

Before implementing the research, the following hypothesis was formulated "Re-parameterised model based on Lithuanian data fits better under Lithuanian conditions (regarding diameter, basal area, height increment and mortality)". This is an integrated hypothesis that requires evaluating tree diameter, basal area, height increment and natural mortality models separately. Accordingly, the growth conditions in Lithuania and in Saxony will be highlighted to show the need for re-parameterisation of growth models used in BWINPro-S.

5.4.1 The growth conditions in Lithuania and in Saxony

Differences in climatic conditions. To compare the climatic conditions in Lithuania and in Saxony, mean annual temperatures and mean annual precipitation in 2009 are used as indicator. According to ŽVILIUS (2010) in 2009 mean annual temperature in Lithuania varied from 8^0C in the west part to 5.5 in the east.

In Eastern Germany, the mean annual temperature in 2009 varied from 9 to 10^0C (WETTERKONTOR 2014). So the mean annual temperature in Eastern Germany was 2-4^0C higher than in Lithuania. The mean annual precipitation in Lithuania, in 2009, varied from 850mm year^{-1} in the west to 600 mm year^{-1} in the central-north and south-west (ŽVILIUS 2010). The mean annual precipitation in eastern Germany, in 2009, varied from 580 to 620 mm year^{-1}. So mean annual precipitation was higher in Lithuania.

These findings suggest that the growth limiting factor in Lithuania is temperature and in Saxony is annual precipitation. However, the overall climatic conditions do not differ remarkably.

Comparison of Lithuanian and Saxon yield tables. The main result of the comparison of Lithuania's and Saxony's yield tables was that the growth conditions of pine trees in

Lithuania and in Saxony differ mainly due to distinct forest management practices. This difference set the basis for the re-parameterisation of forest growth models.

The most stable stand level variable is mean stand height (H_q) and its dynamics over the age. The other variables that describe tree diameter growth are greatly influenced by silvicultural practices. In Saxony, pines grow on sandy soils, thus they probably need longer roots to reach groundwater levels and at $Y^{1\text{-}40}$age grow upwards (height) slower than Lithuanian pines. In $Mat^{101\text{-}140}$age, pines in Saxony grow a little faster than in Lithuania because their roots could exploit the groundwater resources and water availability is no longer a limiting factor. The other explanation could be more related to management practices. In $Mat^{101\text{-}140}$age, in Saxony the smallest tress are removed, leaving 200-300 of the most productive trees. Thus, mean stand height (H_q) increases artificially.

Much more remarkable differences were found while comparing quadratic mean diameter (D_q) or its increment (ZD_q) dynamics over the age. The dissimilarities in Saxony's and Lithuania's yield tables appear to be due to different forest management traditions. German foresters used to plant very dense pine stands. By contrast, Lithuanian foresters used natural regeneration of pine stands more often, and were not, as a result, as dense as those in Saxony. Furthermore, in $Mat^{101\text{-}140}$age, in Saxony, the density is reduced due to the forest management traditions that focuses on the management of target trees with large dimensions. In Lithuania, commercial pine stands are simply cut after 100 years of growth. So taking into account these differences, higher density leads to higher yield levels.

As the practical consequence of these findings, the growth models of Saxony have to be re-parameterised for Lithuanian growth conditions.

This comparison does have some limitations. All the analysed stand level variables are influenced by forest management practices. Thus, comparison has some limitation to express growth differences. Stand top height that is less influenced by density, would be more appropriate for this comparison, however, it is not used in Lithuania yet.

5.4.2 Diameter increment model

The new periodic mean five year diameter increment (i_{d5}) model was developed by this study. The formulated hypothesis asks if this model has at least the same statistical characteristics as the analysed basal area increment models. The i_{d5} model was developed to avoid pseudo linearity that is common to linear logarithmic models. This is the main advantage of this model. Nevetheless, logarithmic transformations of independent and dependent variables could be the reasons for the systematic errors produced by the model.

According to the results, the i_{d5} model managed to explain 48.3% of diameter increment variation. This is a good result compared to the results of PUKKALA (1989) (56%), VETTENRANTA (1999) (58%) and PALAHÍ et al. (2003) (24%).

This study showed a high dependence of the explained proportion of variation on the age of stands used for analysis. If the model had been developed using data of young stands, the explained proportion of the variation would have been more than 70%. By contrast, if the model had been based on $Prem^{81\text{-}100}age$ or especially mature stand data, the explained portion of the variation would have been lower than 30%. So it shows the need to have equal representatives of the various age of stands. In the comparison of the i_{d5} model to the basal area increment models, the explained proportion of the variation was lower for i_{d5} model.

It is worth pointing out that the i_{d5} model satisfies the regression assumptions. The distribution of model's residuals was close or equal to normal and the model's residuals were equally distributed in all the ranges of the modelled values without remarkable deviations. Logarithmic basal area increment models did not have normal distribution of models' residuals. Additionally, the distribution of residuals had some remarkable deviations.

Diameter increment models have good potentials to be used in practice. Diameter increment of trees could be modelled without logarithmic transformations of independent variables.

Diameter increment models do, however, have some weaknesses; primarily it was not validated on independent data. Additionally, although model sensitivity analysis is a sensitive stage in the process of developing a model, it was not done for this model.

Despite some shortcomings discussed, it is possible to conclude that the developed nonlinear tree diameter increment model is a relevant tool for forest growth modelling. The performance of this model should be evaluated for other tree species as well. Indeed, the model needs to be tested in mixed stands, which would reveal if the developed model responds well under more difficult conditions.

5.4.3 Basal area increment models

The original SCHRÖDER et al. (2007) basal area increment model ($SCHRÖDER^{7OR}i_{ba_5}$) was re-parameterised ($SCHRÖDER^{7ReP}i_{ba_5}$) for Lithuanian growth conditions. Since this re-parameterisation was one of the key aspects of the study, the hypothesis was formulated that a "Re-parameterised model based on Lithuanian data fits better under Lithuanian conditions regarding basal area increment". The results confirmed this hypothesis. However, statistical analysis of $SCHRÖDER^{7OR}i_{ba_5}$ model showed reasonably good performance of this model under Lithuanian growth conditions. Thus, the results have to be discussed in more detail.

The $\textit{SCHRÖDER}^{7OR}i_{ba_5}$ model involves height of crown base (h_{cb}) as well as crown width (cw) sub-models under the crown surface area (csa) parameter. This model uses the crown dimensions of trees as the main basal area increment predictors. If a smaller crown size is estimated than the real size, i_{ba_5} values estimated for the tree will be reduced. The results for $\textit{SCHRÖDER}^{7ReP}i_{ba_5}$ (see Figure 4-35 and Figure 4-37) show that the model predicted h_{cb} and cw of trees without any deviations. The residuals were equally distributed in all the ranges of modelled values. By contrast, h_{cb} as well as cw sub-models of $\textit{SCHRÖDER}^{7OR}i_{ba_5}$ produced remarkable systematic deviations (see Figure 4-29 and Figure 4-31). Both sub-models underestimated the values of $Y^{1\text{-}40}$age trees and overestimated the values of $Mid^{41\text{-}80}$age, $Prem^{81\text{-}100}$age or mature trees. So at $Y^{1\text{-}40}$age these sub-models describe the pine trees (grown in Saxony) with smaller crown dimensions and crown surface area than measured in Lithuania. However, $Mid^{41\text{-}80}$age, $Prem^{81\text{-}100}$age or $Mat^{101\text{-}140}$age pines modelled crown surface areas that are close or equal to the crown surface area measured in Lithuania. However the shapes (crown length and crown width) of pines' crowns that grow in Lithuania have longer crown lengths and narrower crown widths than those modelled by $\textit{SCHRÖDER}^{7OR}i_{ba_5}$.

The explanation for these differences can be found in subsection 4.4.1. Yield tables for Lithuania and Saxony show that populations of pine trees at $Y^{1\text{-}40}$age in Saxony are denser than their counterparts in Lithuania. Denser populations mean the crowns are smaller because of greater competition. During later age stages, pines are thinned, reducing competition, and crown width increases. However the crown length can increase only as a result of tree growth in height, so thinning does not initially increase crown length.

The $\textit{SCHRÖDER}^{7OR}i_{ba_5}$, as a result of underestimating both h_{cb} as well as cw values, also underestimated the smallest increments for pine trees (see red Loess line in Figure 4-33). Overestimating crown widths and underestimating crown lengths resulted in estimates for crown surface areas being close to real values.

It seems that the small deviations of $\textit{SCHRÖDER}^{7ReP}i_{ba_5}$ model (Figure 4-39) followed the pattern of deviations of $\textit{SCHRÖDER}^{7ReP}h_{cb}$ model (Figure 4-35). Reduced h_{cb} values for tall trees (h_{cb}>21 m) lead to overestimated i_{ba_5} increment (i_{ba5}>-5) for these trees and so on. The precision of h_{cb} model is, therefore, vital for basal area increment predictions.

Both the original $SCHRÖDER^{7OR}i_{ba_5}$ and the re-parameterised $SCHRÖDER^{7ReP}i_{ba_5}$ models had some difficulties fulfilling the requirements of regression assumptions. For neither model was the distribution of residuals normal, which may have been the result of logarithmic transformations of both the dependent as well as independent variables.

Additional important information is observed when the i_{ba_5} logarithmic model is transformed back to normal scale. According to Figure 4-40a, $SCHRÖDER^{7OR}i_{ba_5}$ model produced remarkable negative systematic bias, when transformed back to normal scale. Inclusion of the transformation factor removed some part of bias, but still meaningful amount remained (Figure 4-40b). The $SCHRÖDER^{7ReP}i_{ba_5}$ model also produced a negative bias, but the bias was remarkably lower (Figure 4-41a). Inclusion of the transformation factor when back transformed to normal scale almost eliminated the bias (Figure 4-41b). The retained element of bias probably is associated with the type of logarithmic model used.

Re-parameterisation of the $SCHRÖDER^{7OR}i_{ba_5}$ model has high practical importance. Using the $SCHRÖDER^{7ReP}i_{ba_5}$ model, BWINPro-S could be used to predict the diameter growth of Lithuanian pine trees.

Future research should focus on developing re-parameterised basal area increment models for other tree species. However, STL simulators were developed to predict the growth of mixed stands, so a more important, but infinitely more complex route of research would be to test the behaviour of i_{ba_5} model in mixed stands.

5.4.4 Height increment model

The analysis of height increment models was needed to answer the hypothesis that a "Re-parameterised model based on Lithuanian data fits better under Lithuanian conditions regarding height increment ". The results confirmed the hypothesis. Although, the study did not conduct any direct statistical check of the original SCHRÖDER (2004) height increment ($SCHRÖDER^{4OR}i_{h5}$) models, the results of indirect tests did support the hypothesis.

Data from the National Forest Inventories of Lithuania and Saxony showed that mean stand height over age increases faster in Lithuania compared with Saxony (Figure 4-42). A similar result was produced by analyses of yield tables for Lithuania and Saxony. They indicate that mean stand height at $Y^{1\text{-}40}$age increases faster in Lithuania than in Saxony, but in $Mat^{101\text{-}140}$age increases faster in Saxony (Figure 4-21). Important distinctions were also found by comparing stand top height (H_{100}) and mean stand height (H_q) relations described by data that comes from the yield tables of Saxony and values estimated in the PEPs in Lithuania (Figure

4-43). The trend line between H_{100} and H_q in the Lithuanian PEPs was steeper. These results show different height growth conditions for pine trees in Lithuania and Saxony. The $SCHRÖDER^{4ReP}i_{h5}$ model confirms that the model is suitable for local conditions in Lithuania, for example densities of trees influence stand level variables. But, since tree densities in Lithuania and Saxony differ significantly, this is the weak point of the presented findings.

Analysis of the *$SCHRÖDER^{4ReP}i_{h5}$ model.* The need to use data from the PEPs to model the data that defined stand top height at the base age (100 years), as it was absent in Lithuanian yield tables, was both the most important and weakest aspect of the re-parameterisation procedure. The distance between H_q and H_{100} reduces with increases in both site fertility and mean stand age. This correlation meant that simple linear regression models were inappropriate but that a logarithmic linear H_{100} model was suitable. The high level of the performance of the model was due to its capabilities in statistical analysis, which were characterised by very high coefficients of determination and fulfilled regression assumptions and made the model suitable for estimating H_{100} values for Lithuanian yield tables.

As a result an important stand level value enriched the data of the Lithuanian yield tables, however, this particular H_{100} model cannot be treated at the same level as other models used in the yield tables. This will only be achieved by improving the model, perhaps by using the National Forest Inventory data.

The $SCHRÖDER^{4ReP}i_{h5}$ model shares the same level of precision as developed H_{100} model (Equation 4-3) with additional possible modelling errors.

As a last step, the formula for the $SCHRÖDER^{4OR}i_{h5}$ model is presented in Equation 3-44. In the context of pine trees in Saxony, the coefficient a_0 is equal to 0 and coefficient a_1 is equal to 1. Thus, relative tree height increment is simply equal to the relative potential of the stand top height increment. However, in the $SCHRÖDER^{4ReP}i_{h5}$ model, the third step (Equation 3-44) is added, enabling tree heights for pines in a stand to increase with the same relative potential.

This model, $SCHRÖDER^{4ReP}i_{h5}$, needs to be further developed and validated under various growth conditions. One of the most important fields for further research is the development of the H_{100} model using Lithuania's National Forest Inventory data, which is the most appropriate and representative of the country's data. This direction of research would also increase the plausibility of the $SCHRÖDER^{4ReP}i_{h5}$ model.

5.4.5 Validation of re-parameterised basal area and height increment models

Data used for analysis. To validate re-parameterised basal area ($\textit{SCHRÖDER}^{7ReP}i_{ba5}$) and height increment ($\textit{SCHRÖDER}^{4ReP}i_{h5}$) models, two validation plots, VP5 and VP7 were used. Although these two VPs, provide good representation of the growth conditions of pines in Lithuania, the validation procedure hardly could be called reliable since only two VPs were used. This is the main weakness of this study.

Basal area increment models. The main results of the $\textit{SCHRÖDER}^{7ReP}i_{ba5}$ model's validation were the remarkable negative bias when growth of trees was modelled from 34 to 59 years (VP5) and the degree of precision when growth of trees was simulated from 60 to 89 years (VP7). These results suggest the model's capabilities to predict diameter growth, are to underestimate for trees at 34-59 years age and to be very precise for trees at 60-89 years age.

The remarkable negative bias in plot VP5 could appear due to a couple of reasons. First, there might have been measurement failures in the field and second, the model tends to underestimate young trees.

There is a 12 year gap between the last two inventories (1996 and 2008) in VP5. During this time, trees' identification numbers were lost and grid positions disappeared. According to Appendix 2, the site index H_{AB} remained fairly static, at around 25m in the inventories of 1983 and 1996, yet at the last inventory in 2008 had increased to 28.4m. Similarly, between the 1996 inventory and the 2008 inventory, the site index D_{AB} displayed a substantial increase increased from 29.6 to 30.8cm. These increases in height and diameter could be either due to extremely intensive self-thinning (480 trees died between the inventories of 1996-2008), or due to measurement errors.

According to the yield tables (KULIEŠIS 1993), at a stocking level equal to 1 and H_{AB}=24m, D_q at 60 years should be 20.5cm. The predicted D_q value was 19.5 centimetres (Table 4-31), which is too small, despite both a slightly higher H_{AB}=25m (see Appendix 2) and a higher stocking level of 1.13-1.2 (see Table 4-28).

Height increment models. The main results for the $\textit{SCHRÖDER}^{4ReP}i_{h5}$ model were that predictions for tree heights when growth of trees was modelled from 34 to 59 years (VP5) were underestimated and overestimated when growth of trees was simulated from 60 to 89 years (VP7). Despite the degree of bias for the two sites being circa 4% - positive (VP7) and negative (VP5) see Table 4-30.

A more important issue of concern is the model's systematic tendency to underestimate the heights of smaller trees and to overestimate the heights of larger trees (Figure 4-58 and Figure

4-60). The biggest values for relative height increment apply to the tallest trees that grow under very low competition. In the context of competing, the tallest trees in a stand normally endure less competition than 'suppressed' trees, the annual increments for which are considerably smaller. However, in the height growth model, which estimates relative tree height increment ($\textit{SCHRÖDER}^{4ReP}i_{h_{rel}}$), the relative potential for stand top height increment is the same for all trees (Equation 4-5), which is the most likely reason for the non-homogeneous distribution of prediction residuals.

Stand level variables. The precision of predicted standing volumes is the most important information at stand level for practical forestry. The model's inherent flaws in underestimating and overestimating tree diameters led to a reduction of the standing volume by 23% on VP5 and an increase by 2.2% on VP7 (see Table 4-31).

In conclusion, this validation procedure while showing the future objects of research and possible outcomes for re-parameterised models is unreliable for drawing any serious conclusions. Far more reliable results would be obtained if the validation procedure of the models was conducted using NFI data collected since 1998 (at the time of going to print the NFI archives hold 16 years of data).

5.4.6 Mortality models

The study hypothesized that a "Re-parameterised model based on Lithuanian data fits better under Lithuanian conditions regarding mortality". The results confirmed the hypothesis with the $\textit{SCHRÖDER}^{7ReP}{}_{NTM}$ model showed better results than $\textit{SCHRÖDER}^{7OR}{}_{NTM}$ according to all statistical parameters and provided better total correct classification by 6.1%.

Furthermore, the mortality likelihood (ML) function for vitality in $\textit{SCHRÖDER}^{7OR}{}_{ML}$ indicates function values (F) higher than 0.3, which are much lower than the estimated mortality rate (Figure 4-52a). It seems that re-parameterising the $\textit{SCHRÖDER}^{7OR}{}_{ML}$ model with the growth conditions of Lithuanian pines, the model overestimates F values. This indicates not only the higher resistance of Saxony pines to natural mortality resulting from population density, but also that they grow on lower quality sites or sandy soils. KULIEŠIS et al. (2012) state that pines growing on poor sites manage to withstand higher population densities than those growing on fertile sites.

The primary focus of the development of the new logistic models of tree mortality was to answer whether or not distance dependent CIs increase a model's performance. A supplementary task was to check whether or not any combination of independent variables would give better results than the re-parameterised model under local conditions.

Despite an increase in the model's complexity and additional data required for modelling, inclusion of distance dependent CIs provided only slightly better results in pure pine stands. These models probably would provide better results in structurally complex mixed or double-layered stands.

A range of tree mortality models based on distance dependent CIs have been developed, some of which are based on standard tree and stand level parameters that are simply available from forest inventories (WYKOFF et al. 1982; HAMILTON 1986; PRETZSCH et al. 2002 and SCHRÖDER et al. 2007). Others used basal area of larger trees (BAL) to describe tree position in the stand (MONSERUD & STERBA 1999; PALAHÍ et al. 2003 and JUTRAS et al. 2003). However, BAL as a variable in the current study displayed extremely poor prediction results.

The new logistic natural tree mortality models, developed by this study, gave slightly better results than the $SCHRÖDER^{7ReP}_{NTM}$ model, which might be because the re-parameterised model already uses the most important independent variables for prediction. However, this study emphasized two independent variables with high prediction capacity: d_{bh} and D_q ratio, showing the tree's position in the stand and recent diameter increment, which reveal the degree of vitality of trees that results from competition.

As neither the $SCHRÖDER^{7ReP}_{NTM}$ model nor the developed models were evaluated by applying independent data, this omission is the weak point of the performed analysis. Furthermore, the models were not tested under the more difficult conditions of mixed stands.

Logistic natural mortality models that can classify correctly more than 80% of growing and dead trees in pure pine stands are valuable tools in predicting natural tree mortality. Future research should check and validate this study's proposed distance independent natural mortality models against National Forest Inventory data. Additionally, the models need to be tested in stands with more complex structures.

5.5 Single tree level simulator in Lithuanian forest management system

The last, but potentially the most far reaching hypotheses of the current study was that a "Single Tree Level Simulator would provide valuable support for decision makers and forest managers to improve forest management in Lithuania". The applicability of a Single Tree Level Simulator (STLS) in Lithuanian forest management system is clearly apparent.

JUODVALKIS & KAIRIŪKŠTIS (2009) state that in Lithuania pre-commercial thinning should normally be done 1-2 times and commercial thinning 2-3 times before final cutting. Intermediate cuttings regulate species' composition, wood quality and productivity of stands.

KULIEŠIS et al. (2011) argue that an insufficient quantity of intermediate cuttings occurs in Lithuania by stating that pre-commercial as well as commercial thinning have in most cases been done only once. They also state that intermediate cuttings comprised 47% of the total cuttings in 1996-2000 years and made up only 29% of the total cuttings in 2009.The share of sanitary cuttings made up 68% of intermediate cuttings in 1996-2000 and 61% in 2006-2009. Essentially, the frequency of intermediate cuttings in Lithuania is insufficient and unbalanced (KULIEŠIS et al. 2011).

Forest management in Lithuania is based on the strategic document of the forest management scheme and on the tactical document of the forest management plan (MINISTRY OF ENVIRONMENT 2006). The forest management scheme defines forest management regimes and forest management plans and sets forestry practices in certain forestry estates. Planning, therefore, is done at estate level rather than at stand level. Furthermore, any forest management model other than that officially provided could be more productive under local growth conditions. Finally, models of pure stands simply do not work in mixed stands.

Modern forestry requires computer based forest management tools that aid management in reaching maximum productivity under various growth conditions. A STLS provides forest management alternatives for pure stands oriented to a particular result. It also provides scientifically proved results showing the importance of well-timed thinning of optimal intensity. STLS could be created and applied in Lithuanian forestry (LINKEVIČIUS et al. 2011).

The usage of STLS is not new in countries with lengthy forestry traditions, e.g. German forestry practice uses SILVA (PRETZSCH et al. 2002) and BWINPro (DÖBBELER et al. 2007) and Austrian foresters use PROGNAUS (STERBA & MONSERUD 1997).

The main threat to the practical implementation of STLS is the inertia of forest management traditions that resist change. Forest yield tables have been applied for more than 40 years and have developed deep roots in the mentality of foresters and forest management practice. They have adopted and rigidly apply stand level forest growth models and view any deviation from this practice as a serious infringement of predefined rules. The Lithuanian forester of the 21st Century is an executive forest manager in an environment that is strictly controlled.

The impulse for changes in forest management in Lithuania came from Saxony, Technische Universität Dresden. Cooperation between Technische Universität Dresden and Aleksandras Stulginskis University has already borne fruitful results. It is important that science is reflected in practice. Forest management has to recognise that scientific and popular literature and other forms of cultural and societal cooperation are both beneficial and useful.

RECOMMENDATIONS

1. The elaborated top height model for pine stands is an important tool for the prediction of the growth behavior of pine stands with different densities and thinning regimes.
2. Methodical solutions used for modelling growth and mortality of individual pine trees in pure stands should be applied to mixed pine-spruce stands as well as mixed spruce-broadleaved stands.
3. The elaborated growth models for pure pine stands growth and self-thinning are recommended for use in the prediction of the development pine stands in the National Forest Inventory.

SUMMARY

Objectives

In Lithuania, during the most recent decades, the leading theory in forest management and planning combined optimization of forest stand density and maximal productivity at every time point of stand development. Thus, great effort was spent in creating stand level models that are highly effective in managing even-aged monocultures of pine or spruce forests. But these models produce significant errors in mixed or converted forests. In order to meet the requirements of contemporary forestry, appropriate forest management tools are required that would be capable to predict the growth and yield of more structured forests.

Thus, the overall objective for this study was to re-parameterise the single tree level simulator BWINPro-S (developed for forests in Saxony/Germany) for Lithuanian pine forests that grow on mineral sites.

To reach this goal, the following tasks were set:

- To create, and to evaluate, a database for modelling.
- To estimate the impact of competition for growing space on diameter, basal area and height growth of trees.
- To develop a tree diameter model, and re-parameterise basal area and height growth models.
- To assess natural tree mortality induced by competition between trees for growing space.
- To develop the first approach of STLS for pine in Lithuania.

Hypotheses

1. Site quality is the most important factor that affects forest growth and yield.
2. Distance dependent Competition Indices had higher partial correlation with tree basal area and height increment than distance independent Competition Indices.
3. The re-parameterised model based on Lithuanian data fits better under Lithuanian conditions (regarding diameter, basal area, height increment and mortality) than the original model BWINPro-S.
4. A single tree level simulator provides valuable support for decision makers and forest managers to improve forest management in Lithuania.

Materials and methods

To reach the main goals of this study, the research was structured to four sections: 1) Database completion, 2) Analysis of competition, 3) Modelling tree growth, 4) Validation of developed models.

The database consisted of analytical data from 18 permanent experimental plots (PEPs) and 2 Validation Plots (VP) that were used only for the validation of the models. All plots (PEPs and VP) represent mainly naturally regenerated, single-layered pine stands that grow on very typical pine sites. Database completion involved (a) establishment of the initial database, (b) modelling of missing data values and (c) evaluation of the complete database, which focused on:

- Sample size and estimation of the population's mean
- Estimation of potential site productivity
- Estimation of relationship between potential site productivity and forest yield

In order to estimate the impact of competition for growing space on diameter, basal area and height growth of trees the following methods were used. To select the competitors, this study focuses on three separate positions for setting the inverse cone: a) at the height of the crown base, b) at the height of widest crown width, and c) at the stem base. The opening angle of the search cone was either 60 or 80 degrees. To estimate the competition, the study by partial correlation analysis evaluated a total of 20 competition indices, of which six distance dependent and two distance independent CIs were applied in the research programme. Modelling of tree growth was divided into three parts: a) development of an original tree diameter increment model, b) re-parameterisation of basal area and height increment models, and c) development of new natural mortality models and re-parameterisation of natural mortality models.

Simple linear regression models were evaluated by estimating each model's statistical significance and coefficient of determination. Statistical analysis of multiple linear regression models was enlarged by conducting further tests: statistical significance was checked for each independent variable: regression assumptions (concerning normal distribution and homogeneity of variance of the models's residuals, and multicollinearity of the independent variables) were checked.

Simple nonlinear regression models were evaluated mainly by adjusted coefficient of determination. For multiple nonlinear regression models, regression assumptions were also checked by producing normal Q-Q plots and by checking homogeneity of variance of model's residuals.

Multiple logistic regression models were evaluated by estimating each model's statistical significance with Pearson's chi square statistics and the statistical significance of each model's parameters with Wald statistics. Goodness of fit was estimated by using log likelihood function values, Cox-Snell and Nagelkerkle's coefficients of determination, classification tables and ROC curves.

The re-parameterised basal area and height increment models were validated by plotting each model's modelled values against measured values. Also each model's residuals were plotted against modelled values. Bias, relative bias, precision, relative precision, accuracy and relative accuracy when comparing modelled and measured values were estimated as well.

Results and Conclusions

The growth models used in the BWINPro-S simulator were successfully re-parameterised for Lithuanian growth conditions. Thus the study may state these conclusions:

1. The accumulated standing volumes and overall productivity of pine stands only partially depends on the productivity potential of sites. Site quality defines the growth potential that could be reached in a stand. The realization of growth potential largely depends on the growing regime in the stand that is defined by the beginning, frequency and intensity of thinning.
2. In pure pine stands, distance dependent competition indices show greater capabilities to predict mean annual basal area increment than distance independent indices. Competition index (coded as CI_4 in this study) proposed by BIGING & DOBBERTIN (1992) combined with the selection method height to crown base with opening angle of 80 degrees is recommended as the most efficient for describing the individual diameter growth of trees.
3. HEGYI'S (1974) distance independent competition index scored the highest partial correlation coefficients and produced slightly better results than distance dependent competition indices in predicting mean annual height increment for individual trees. Yet, the generally poor performance of competition indices to predict height increment of individual pine trees was also recorded.
4. Competition has a purely negative impact on tree diameter growth. Increasing competition leads to steady decreases in diameter increment. Nevertheless, although a small amount of competition does stimulate tree height growth, stronger competition has a lasting negative impact on tree height growth.

5. The nonlinear diameter increment model, developed by this study, has high capabilities to predict growth of pine trees. The model's coefficient of determination value was equal to 0.483. The distribution of the model's residuals fulfilled the requirements of regression assumptions.
6. The re-parameterisation of the BWINPro-S basal area and height increment models for use in Lithuanian permanent experimental plots, increased their performance. During the first validation procedure, based on 30 years growth simulation, the re-parameterised models produced reliable results.
7. Two individual mortality models, developed by this study, showed very high capabilities to predict the natural mortality of pine trees. The distance dependent natural mortality model scored slightly better results. Both models managed to correctly classify dead and living trees, slightly more than 83% of the time. The re-parameterisation of the BWINPro-S natural mortality model increased its ability to predict the natural mortality of pine trees in Lithuania. Correctly classifying growing and dead trees increased by 6%, from 77 to 83%.
8. BWINPro-S simulator with re-parameterised growth models for Lithuanian conditions is a valuable support tool for decision makers and forest managers in Lithuania.

ZUSAMMENFASSUNG

Ziele

Die Forsteinrichtung in Litauen war in den vergangenen Jahrzehnten vom Leitgedanken geprägt, die Optimierung der Bestandsdichte und die Maximierung der Produktivität in jeder Phase der Bestandsentwicklung als gleichrangige Ziele zu betrachten. Deshalb wurden große Anstrengungen in die Herleitung von Bestandswuchsmodellen für gleichaltrige Kiefern- oder Fichtenreinbestände gelegt. Bei der Anwendung dieser Modelle auf gemischte oder in der Umwandlung befindliche Wälder sind allerdings nur ungenaue Resultate zu erzielen. Um den Erfordernissen einer zeitgemäßen Forstwirtschaft gerecht zu werden, sind geeignete Instrumente zur Prognose von Wachstum und Ertrag strukturreicher Wälder vonnöten. Das Hauptziel dieser Arbeit bestand deshalb in der Neuparametrisierung des Einzelbaumwachstumssimulators BWINPro-S (entwickelt für sächsische Wuchsverhältnisse) für Kiefernwälder auf mineralischen Standorten in Litauen.

Zur Zielerreichung dienten folgende Schritte:

- Schaffung und Evaluierung einer Datengrundlage für die Modellierung.
- Abschätzung der Effekte von Konkurrenz um Wuchsraum auf den Durchmesser-, Grundflächen- und Höhenzuwachs von Einzelbäumen.
- Entwicklung eines Durchmesser-Zuwachsmodells sowie Neuparametrisierung der Grundflächen- und Höhenwachstumsmodelle.
- Bestimmung der Einzelbaummortalität durch Konkurrenz um Wuchsraum.
- Entwicklung eines ersten Ansatzes für einen Einzelbaumwachstumssimulator für Kiefer in Litauen.

Hypothesen:

1. Die Standorteigenschaften sind der prägende Faktor für Wachstum und Ertrag von Waldbeständen.
2. Distanzabhängige Konkurrenzindizes zeigen höhere partielle Korrelationen zu Grundflächen- und Höhenzuwachs der Einzelbäume als distanzunabhängige Konkurrenzindizes.
3. Im Vergleich zum Ursprungsmodell BWINPro-S kann durch die Neuparametrisierung eine bessere Anpassung an die Wachstumswirklichkeit in Litauen erzielt werden (in

Bezug auf Durchmesser-, Grundflächen- und Höhenzuwachs sowie Mortalitätsschätzung).

4. Ein Einzelbaumwachstumssimulator unterstützt die Entscheidungsträger und Forstplaner in Litauen bei der Optimierung der Waldbewirtschaftung ganz wesentlich.

Material und Methoden

Der Forschungsansatz gliederte sich wie folgt:

1) Vervollständigung der Datengrundlage.

2) Analyse der Konkurrenzverhältnisse.

3) Modellierung des Einzelbaumwachstums.

4) Validierung der neuentwickelten bzw. neuparametrisierten Modelle.

Die Datengrundlage bestand aus Messwerten von 18 Dauerversuchsflächen (PEP) und zwei Validierungsflächen (VP), von denen letztere nur zur Modellüberprüfung herangezogen wurden. Auf allen Flächen stocken vorwiegend aus Naturverjüngung hervorgegangene, einschichtige Kiefernbestände auf kieferntypischen Standorteinheiten. Die Vervollständigung der Datengrundlage erforderte (a) die Erzeugung der Ausgangsdatenbasis, (b) Berechnung fehlender Werte, und (c) Evaluierung der vervollständigten Datengrundlage. Dabei lag das Hauptaugenmerk auf:

- Stichprobenumfang und Schätzung der Populationsmittelwerte.
- Schätzung des potentiellen Standort-Leistungsvermögens.
- Analyse der Beziehung zwischen dem potentiellen Standort-Leistungsvermögen und dem tatsächlichen Waldertrag.

Zur Abschätzung der Effekte von Konkurrenz um Wuchsraum auf den Durchmesser-, Grundflächen- und Höhenzuwachs von Einzelbäumen diente folgendes Vorgehen: Zur Konkurrentenidentifikation wurde ein inverser Lichtkegel mit einem Öffnungswinkel von 60 und 80 Grad konstruiert, dessen nach unten gerichtete Spitze (a) an der Kronenansatzhöhe, (b) an der Höhe der größten Kronenbreite, und (c) am Stammfuß des Zentralbaumes ansetzte. Zur Quantifizierung des Konkurrenzdrucks wurden mit Hilfe der partiellen Korrelationsanalyse 20 Konkurrenzindizes geprüft, von denen letztendlich sechs distanzabhängige und zwei distanzunabhängige Indizes in der weiteren Auswertung Berücksichtigung fanden. Die Modellierung des Einzelbaumwachstums erfolgte in drei Schritten: (a) Entwicklung eines originären Einzelbaum-Durchmesserzuwachsmodells, (b) Neuparametrisierung des

Grundflächen- und Höhenzuwachsmodells, und (c) Entwicklung und Neuparametrisierung von Mortalitätsmodellen.

Zur Bewertung einfacher linearer Regressionsmodelle wurden die statistische Signifikanz und das Bestimmtheitsmaß herangezogen. Bei multiplen linearen Regressionsmodellen wurde die Signifikanz jeder unabhängigen Variablen gesondert geprüft (hinsichtlich Normalverteilung, Varianzhomogenität der Residuen und Multikollinearität).

Zur Bewertung einfacher nichtlinearer Regressionsmodelle diente in erster Linie das korrigierte Bestimmtheitsmaß, bei multiplen nichtlinearen Regressionsmodellen fanden darüber hinaus Q-Q-Plots (Quantil-Quantil-Diagramme) und die Prüfung auf Varianzhomogenität der Residuen Verwendung.

Die Evaluierung multipler logistischer Regressionsmodelle erfolgte mit Pearsons Chi-Quadrat-Test, die Signifikanz jedes Modellparameters wurde mit der Wald-Statistik geprüft. Die Anpassungsgüte wurde mit Hilfe der Log-Likelihood-Funktion, Cox & Snell- bzw. Nagelkerke-Bestimmtheitsmaßen, Klassifikationstabellen und ROC-Kurven bewertet.

Zur Prüfung der neuparametrisierten Grundflächen- und Höhenzuwachsmodelle wurden die modellierten Werte gegen die Messwerte und darüber hinaus die Residuen gegen die Modellwerte geplottet. Außerdem wurden zur Beurteilung die Verzerrung, die Präzision und die Treffgenauigkeit (sowohl als Absolut- als auch als Relativwerte) herangezogen.

Ergebnisse und Schlussfolgerungen

Die Wachstumsmodelle des Simulators BWINPro-S konnten erfolgreich an die Bedingungen in Litauen angepasst werden. Daraus lassen sich folgende Schlussfolgerungen ableiten:

1. Der stehende Vorrat und die Gesamtwuchsleistung von Kiefernbeständen werden nur z. T. vom standörtlichen Leistungsvermögen determiniert. Die Standorteigenschaften bestimmen das theoretische Leistungsvermögen von Beständen. Ob dieses Potential auch tatsächlich ausgeschöpft werden kann, hängt weitgehend von der Bewirtschaftungsart ab, die geprägt ist durch Beginn, Häufigkeit und Stärke der Durchforstungseingriffe.
2. In Kiefernreinbeständen eignen sich distanzabhängige Konkurrenzindizes besser zur Prognose des mittleren Grundflächenzuwachses als distanzunabhängige Indizes. Zur Beschreibung des Einzelbaum-Durchmesserzuwachses hat sich der Index nach BIGING & DOBBERTIN (1992, in dieser Arbeit als Index CI_4 bezeichnet) in Kombination mit der Konkurrentenidentifikationsmethode „Suchkegelansatz in Kronenansatzhöhe, Öffnungswinkel 80 Grad“ als der bestgeeignetste Ansatz erweisen.

3. Der distanzunabhängige Konkurrenzindex nach HEGYI (1974) erreichte die höchsten partiellen Korrelationskoeffizienten mit den mittleren Einzelbaum-Höhenzuwächsen und ergab etwas bessere Resultate bei der Wachstumsprognose als distanzabhängige Indizes. Allerdings waren die Beziehungen zwischen den Konkurrenzindizes und den Einzelbaum-Höhenzuwächsen nur schwach ausgeprägt.
4. Konkurrenz wirkt sich dämpfend auf den Einzelbaum-Durchmesserzuwachs aus, bei zunehmender Konkurrenz sinkt der Zuwachs kontinuierlich ab. Im Gegensatz dazu beschleunigt leichte Konkurrenz das Einzelbaum-Höhenwachstum, bei starker Konkurrenz jedoch wird auch der Höhenzuwachs negativ beeinflusst.
5. Das im Rahmen dieser Arbeit hergeleitete nichtlineare Durchmesserzuwachsmodell ist zur Prognose des Kiefernwachstums bestens geeignet, das Bestimmtheitsmaß beträgt 0,483, die Residuen waren normalverteilt.
6. Die Neuparametrisierung des Grundflächen- und Höhenzuwachsmodells verbesserte die Anpassung an die Wuchsbedingungen in Litauen bedeutend. Eine erste Validierung, durchgeführt für eine Wachstumsprognose über einen 30-jährigen Zeitraum, ergab zufriedenstellende Ergebnisse.
7. Die zwei im Rahmen dieser Arbeit hergeleiteten Mortalitätsschätzer sind zur Vorhersage der natürlichen Absterbeprozesse in den Kiefernbeständen gut geeignet. Beide Ansätze klassifizierten lebende und tote Bäume mit einer Treffgenauigkeit von über 83%, während der in BWINPro-S enthaltene Schätzer nur 77% der Bäume korrekt zuordnete.
8. Der für litauische Verhältnisse neuparametrisierte Wachstumssimulator BWINPro-S ist ein wichtiges Instrument zur Entscheidungsunterstützung für Forstplaner in Litauen.

SANTRAUKA

Darbo tikslai

Lietuvoje ilgą laiką ūkininkavimas miškuose buvo grindžiamas medynų tankumo optimizavimu ir maksimalaus medynų produktyvumo siekimu visose medynų vystymosi stadijose. Mokslininkai dėjo daug pastangų kurdami medyno lygmens našumo modelius. Šie modeliai buvo patikimi ūkininkaujant vienaamžiuose medynuose. Tačiau jie yra sunkiai pritaikomi mišriuose medynuose. Siekiant patenkinti šiuolaikinio miškininkavimo poreikius, kai vis didesnis dėmesys skiriamas mišrių medynų su keliais ardais auginimui, reikalingi nauji modeliai, kurie sėkmingai prognozuotų mišrių medynų augimą, jų našumą bei reakcijas į įvairias ūkines priemones.

Todėl pagrindinis šio darbo tikslas yra parametrizuoti iš naujo BWINPro-S medžio lygio stimuliatorių sukurtą Vokietijos rytinėje žemėje Saksonijoje taip pritaikant jį Lietuvos sąlygoms.

Šiam tikslui pasiekti, buvo suformuluoti sekantys uždaviniai:

- Paruošti ir įvertinti duomenų bazę reikalingą modeliavimui.
- Įvertinti medžių tarpusavio konkurencijos įtaką medžių skersmens, skerspločių sumos ir aukščio prieaugiui.
- Sukurti naują medžio skersmens prieaugio modelį ir parametrizuoti iš naujo skerspločių sumos bei aukščio modelius.
- Įvertinti pušynų savaiminio retinimosi dėsningumus atsižvelgiant į medžių tarpusavio konkurenciją dėl augimo erdvės.

Tikrintinos hipotezės:

1. Medyno augavietė yra svarbiausias veiksnys, lemiantis medynų našumą ir produktyvumą.
2. Konkurencijos indeksai, įvertinantys atstumą tarp medžių, turi didesnes dalinės koreliacijos reikšmes su medžių skerspločių sumos, skersmens ir aukščio prieaugiais lyginant su konkurencijos indeksais, neįvertinančiais atstumo tarp medžių.
3. Parametrizuoti naujai, panaudojant Lietuvoje augančių pušynų duomenis, modeliai geriau tinka Lietuvos sąlygoms (pagal skersmens, skerspločių sumos ir aukščio prieaugį bei savaiminį retinimąsi) lyginant su modeliais, sukurtais Vokietijos sąlygoms.

4. Medžio lygmens augimo simuliatorius yra naudinga priemonė miškų valdytojams siekiant pagerinti ūkininkavimo kokybę Lietuvoje.

Darbo metodai

Šis darbas buvo suskirstytas į keturias pagrindines dalis: 1) duomenų bazės suformavimas, 2) konkurencijos indeksų analizė, 3) medžių augimo modeliavimas, 4) augimo modelių patikrinimas.

Duomenų bazę sudarė 20 pastovių tyrimo barelių, iš kurių 18 buvo skirti modelių kūrimui ir 2 modelių patikrinimui. Tyrimo bareliai buvo įsteigti natūraliai atsikūrusiuose vienaardžiuose pušynuose, augančiuose tipingose pušiai augavietėse. Duomenų bazės įvertinimas buvo atliekamas tokiais etapais: (a) pirminės duomenų bazės suformavimas, (b) trūkstamų matavimų modeliavimas ir (c) duomenų bazės įvertinimas yra grindžiamas:

- Imties dydžiu ir populiacijos vidurkio nustatymo tikslumu.
- Potencialaus medynų našumo įvertinimu.
- Ryšių tarp potencialaus medynų našumo ir medynų našumo bei produktyvumo įvertinimu.

Vertinant konkurencijos įtaką medžių skersmens, skerspločių sumos ir aukščio prieaugiui, buvo naudoti konkurentų parinkimo ir konkurencijos įvertinimo metodai.

Konkuruojantys medžiai buvo atrenkami pagal apversto kūgio viršūnę, sutapatintą su tiriamojo medžio a) lajos pradžia, b) plačiausia lajos vieta, ir c) medžio šaknies kakleliu. Kūgio kampas buvo keičiamas nuo 60 iki 80 laipsnių. Iš viso buvo tiriama dvidešimt konkurencijos indeksų (du konkurencijos indeksai, nepriklausantys nuo atstumo tarp medžių ir aštuoniolika konkurencijos indeksų, priklausančių nuo atstumo tarp medžių). Konkurencijos indeksai vertinti taikant dalinės koreliacijos metodus.

Medžių augimo modeliavimas buvo atliekamas trim etapais: a) originalaus medžių skersmens prieaugio modelio sukūrimas, b) medžių skerspločių sumos ir medžių aukščio prieaugio modelių parametrizavimas naujai, c) sukūrimas originalių ir parametrizavimas naujai jau esamų natūralaus retinimosi modelių.

Paprastieji tiesinės regresijos modeliai buvo vertinami naudojant jų statistinį reikšmingumą ir skaičiuojant determinacijos koeficientą. Daugialypių tiesinės regresijos modelių statistinė analizė buvo išplėsta papildomais testais: statistinis reikšmingumas tiriamas kiekvienam nepriklausomam kintamajam, taip pat vertinama ar modelis tenkina pagrindines regresijos sąlygas (nepriklausomi kintamieji nėra tarpusavyje susieti, modelio liekanos turi normalųjį skirstinį, yra tolygiai išsidėstę).

Paprastieji netiesinės regresijos modeliai buvo vertinami skaičiuojant koreguotąjį determinacijos koeficientą. Atliekant daugialypių netiesinės regresijos modelių analizę taip pat buvo tikrinama ar tenkinamos regresijos sąlygos.

Logistiniai savaiminio retinimosi modeliai buvo vertinami naudojant šiuos statistinius parametrus: modelio X^2 suderinamumo kriterijų, Voldo kriterijų, didžiausio tikėtinumo funkcijos vertę, Kokso-Snelo ir Nagelkerkės pseudodeterminacijos koeficientus, klasifikavimo lenteles ir klasifikatoriaus jautrumo ir specifiškumo (ROC) kreives.

Parametrizuoti naujai medžių skerspločių sumos ir medžių aukščio prieaugių modeliai buvo tikrinami lyginant modeliuotas medžių skersmens ir aukščio reikšmes su realiai išmatuotomis reikšmėmis analizuojamo periodo pabaigoje. Taip pat buvo tiriamas modelių liekanų išsidėstymas modeliuojamų verčių atžvilgiu. Galiausiai, poslinkio, santykinio poslinkio, tikslumo, santykinio tikslumo, tikslumo be poslinkio ir santykinio tikslumo be poslinkio buvo naudojami vertinant modelių prognozes.

Rezultatai ir išvados

Augimo modeliai, naudojami BWINPro-S medžio lygio simuliatoriuje, buvo sėkmingai parametrizuoti naujai ir pritaikyti Lietuvos sąlygoms.

Remiantis šio darbo rezultatais, buvo gautos sekančios išvados:

1. Sukauptas tūris ir bendras medynų našumas pušynuose tik dalinai priklauso nuo potencialaus augaviečių derlingumo. Augavietės sąlygos lemia tik potencialų medynų našumą kuris gali būti pasiektas medyne. Ar potencialus augavietės našumas bus realizuotas priklauso nuo medžių auginimo rėžimo, kuris apibūdinamas ugdomųjų kirtimų pradžia, kartojimų dažnumu ir jų intensyvumu.
2. Grynuose pušynuose, konkurencijos indeksai, įvertinantys atstumą tarp medžių turi didesnes galimybes prognozuoti skerspločių sumos prieaugį negu konkurencijos indeksai, neįvertinantys atstumo tarp medžių. Konkurencijos indeksas CI_4, pasiūlytas BIGING & DOBBERTIN (1992), grindžiamas konkurentų parinkimu pagal apverstą 80 laipsnių kūgį, kurio viršūnė yra sutapatinama su medžių lajos pradžia yra rekomenduojamas kaip pats efektyviausias modeliuojant medžių skersmens prieaugį.
3. HEGYI (1974) konkurencijos indeksas, neįvertinantis atstumo tarp medžių tiriant konkurencijos indeksų įtaką medžių aukščio prieaugiui, parodė kiek geresnius dalinės koreliacijos rezultatus negu kad konkurencijos indeksai, įvertinantys atstumą tarp medžių. Tyrimų rezultatai parodė gana silpną konkurencijos indeksų galimybę prognozuoti medžių aukščio prieaugį.

4. Konkurencija turi išskirtinai neigiamą įtaką medžių skersmens prieaugiui. Didėjanti konkurencija lemia mažėjantį skersmens prieaugį. Nedidelė konkurencija padidina medžių aukščio prieaugį. Tačiau stipresnė konkurencija taip pat turi neigiamą įtaką medžių aukščio prieaugiui.
5. Originalus skersmens prieaugio modelis turi geras galimybes prognozuoti pušies medžių augimą. Šio modelio determinacijos koeficientas buvo lygus 0.483. Modelio liekanos turėjo normalųjį skirstinį ir buvo tolygiai pasiskirsčiusios modeliuojamų verčių atžvilgiu.
6. Parametrizuoti naujai BWINPro-S medžių skerspločių sumos ir medžių aukščio prieaugio modeliai, panaudojant Lietuvos pušynų pastovių tyrimo barelių duomenis, padidino jų prognozavimo galimybes. Pirmieji modelių tikrinimo rezultatai pagrįsti trisdešimties metų augimo prognozėmis, parodė, kad šie modeliai yra patikimi.
7. Du originaliai sukurti pušynų savaiminio retinimosi modeliai pasižymi geromis galimybėmis prognozuoti pušynų savaiminį išsiretinimą. Savaiminio retinimosi modelis, atsižvelgiantis į atstumą tarp medžių pasižymi geresnėmis galimybėmis prognozuoti pušynų savaiminį retinimąsi negu savaiminio retinimosi modelis, neatsižvelgiantis į atstumą tarp medžių. Abu modeliai teisingai klasifikavo daugiau negu 83% augančių ir savaime išsiretinančių medžių. BWINPro-S savaiminio retinimosi modelio parametrizavimas naujai padidino jo teisingai prognozuojamų augančių ir savaime išsiretinančių medžių dalį šešiais procentais, nuo 77 iki 83%.
8. Medžio lygio augimo simuliatorius BWINPro-S su parametrizuotais naujai augimo modeliais yra naudingas įrankis Lietuvos miškų augintojams.

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APPENDIX

Acronyms and abbreviations

$\bar{D}$	Mean tree diameter at breast height in cm
$\bar{H}$	Mean tree height in m
$\overline{HCB}$	Mean height to crown base in m
$\overline{CW}$	Mean crown width in m
BA	Basal area of remaining stand [m^2]
ba	Tree basal area [cm^2]
$BA_{removed}$	Basal area of removed stand [m^2]
CI_1 and CI_2	Distance independent competition indices (see Table 3-3)
$CI_3 \ldots CI_8$	Distance dependent competition indices (see Table 3-3)
cl	Crown length in m
Coeff Values	Values of coefficients
cw	Crown width in m
D_{100}	Mean diameter of 100 largest trees per ha or stand top diameter in cm
D_{AB}	Site productivity index according to the stand mean diameter at base age (100 years) in cm
d_{bh}	Tree diameter at breast height in cm
D_q	Quadratic mean diameter of remaining stand in cm
$D_{q\ removed}$	Quadratic mean diameter of removed stand in cm
GY	Gross volume yield [$m^3\ ha^{-1}$]
h	Tree height in m
H_{100}	mean height of 100 largest trees per ha or stand top height in m
H_{AB}	Site productivity index according to the mean stand height at base age (100 years) in m
HCB 80	Competitor selection method height to crown base with opening angle of 80 degrees
H_q	Mean stand height of remaining stand in m
$H_{q\ removed}$	Mean height of removed stand in m
HWCW 60	Competitor selection method height to widest crown width with opening angle 60 degrees
i_{ba}	Periodic mean annual tree basal area increment [cm^2]
i_h	periodic mean annual tree height increment in m
inv	Inventory year
ln	Natural logarithm
MSA	Mean stand age in years
N	Number of growing trees ha^{-1}
$N_{removed}$	Number of self-thinned trees ha^{-1}
PAI_v	Periodic annual volume increment [$m^3\ ha^{-1}$]
Partial corr	Partial correlation
PEP	Permanent experimental plot
r	Pearson correlation coefficient
R^2	Coefficient of determination
SB 60	Competitor selection method stem base with opening angle 60 degrees
Sign	Model's significance
Sign of coeff	Significance of each coefficient in the model
Sp	Tree species
Std Error of coeff	Standard errors of coefficients
V	Standing volume [$m^3\ ha^{-1}$]
$V_{removed}$	Volume of removed stand [$m^3\ ha^{-1}$]

Appendix 1: Estimation of standard deviation of mean stand level variables.

PEPs	inv	$\bar{D}$	Deviation %	Deviation cm	$\bar{H}$	Deviation %	Deviation m	$\bar{H}_{CB}$	Deviation %	Deviation m	$\bar{CW}$	Deviation %	Deviation m
81	1984	24.32	3.62	0.88	22.78	3.42	0.78	15.15	3.62	0.55			
82	1984	16.58	3.25	0.54	15.91	2.16	0.34	10.23	2.19	0.22			
83	1984	25.78	2.13	0.55	24.31	2.09	0.51	17.76	1.82	0.32			
84	1984	18.35	2.31	0.42	19.74	1.82	0.36	13.87	1.77	0.25			
85	1984	19.6	2.54	0.5	19.26	2.38	0.46	14.03	2.52	0.35			
86	1984	11.62	2.71	0.32	12.19	3.56	0.43	8.97	2.66	0.24			
87	1984	14.52	3.42	0.5	14.8	3.62	0.54	10.67	2.28	0.24			
88	1984	10.43	2.72	0.28	12.69	2.36	0.3	9.91	2.21	0.22			
89	1984	13.96	2.64	0.37	14.99	2.37	0.36	11.02	2.08	0.23			
90	1984	20.19	2.5	0.51	19.21	2.94	0.57	14.29	2.17	0.31			
91	1984	28.62	3.24	0.93	27.4	3.08	0.84	18.98	3	0.57			
92	1984	17.76	3.2	0.57	16.69	3.89	0.65	11.59	3.34	0.39			
93	1984	12.14	3.77	0.46	10.93	4.95	0.54	6.06	5.01	0.3			
94	1984	21.16	2.8	0.59	18.24	2.91	0.53	11.56	3.2	0.37			
95	1984	18.01	3.09	0.56	16.52	3.25	0.54	11.11	3.24	0.36			
96	1984	10.3	4.33	0.45	11.38	4.5	0.51	8.14	4.19	0.34			
201	1984												
206	1984												
Average value			3.02	0.53		3.08	0.52		2.83	0.33			
Minimum value			2.13	0.28		1.82	0.3		1.77	0.22			
Maximum value			4.33	0.93		4.95	0.84		5.01	0.57			
81	1988	26.1	3.71	0.97	23.56	3.21	0.76	15.8	3.03	0.48			
82	1988	18.91	3.57	0.67	17.49	2.43	0.43	11.05	2.51	0.28			
83	1988	27.35	2.19	0.6	25.34	1.73	0.44	18.92	1.43	0.27			
84	1988	21.26	2.61	0.56	21.61	1.51	0.33	15.15	1.58	0.24			
85	1988	21.35	2.57	0.55	20.55	1.93	0.4	15.72	1.8	0.28			
86	1988	12.92	2.92	0.38	13.19	3.65	0.48	9.97	2.78	0.28			
87	1988	16.18	3.55	0.57	16.24	3.34	0.54	12.02	2.4	0.29			
88	1988	11.86	3.04	0.36	14.17	2.18	0.31	10.77	1.77	0.19			
89	1988	15.87	2.82	0.45	16.4	2.25	0.37	11.81	1.89	0.22			
90	1988	21.2	2.58	0.55	20.09	2.81	0.56	14.61	2.07	0.3			
91	1988	30.09	3.19	0.96	28.24	2.66	0.75	19.49	2.09	0.41			
92	1988	19.43	3.27	0.64	17.86	3.41	0.61	12.73	2.36	0.3			
93	1988	13.47	3.77	0.51	12.24	4.35	0.53	8.13	3.55	0.29			
94	1988	22.67	2.91	0.66	19.05	2.72	0.52	12.82	2.22	0.28			
95	1988	19.64	3.17	0.62	17.49	2.94	0.51	11.97	2.88	0.34			
96	1988	11.79	4.54	0.54	12.67	3.86	0.49	9.39	3.5	0.33			
201	1988	2.19	2.58	0.06	1.56	3.92	0.06						
206	1988	0.19	9.99	0.02	0.96	1.96	0.02						
Average value			3.5	0.54		2.83	0.45		2.37	0.3			
Minimum value			2.19	0.02		1.51	0.02		1.43	0.19			
Maximum value			9.99	0.97		4.35	0.76		3.55	0.48			
81	1994	26.84	3.69	0.99	24.02	3.16	0.76	16.03	3.21	0.51			
82	1994	20.69	4.1	0.85	19.18	3.07	0.59	12.53	1.98	0.25			
83	1994	28.19	2.24	0.63	26.24	1.69	0.44	19.21	1.49	0.29			
84	1994	22.45	2.77	0.62	22.46	1.7	0.38	15.4	1.59	0.25			
85	1994	22.6	2.71	0.61	21.62	2.05	0.44	16.09	1.74	0.28			
86	1994	14.38	3.11	0.45	14.79	3.87	0.57	10.66	2.79	0.3			
87	1994	17.32	3.64	0.63	17.3	3.56	0.62	12.52	2.5	0.31			
88	1994	13.26	3.34	0.44	15.33	2.97	0.46	11.43	2.01	0.23			
89	1994	17.39	2.93	0.51	17.75	2.4	0.43	12.85	2.02	0.26			
90	1994	23.07	2.78	0.64	21.49	2.85	0.61	14.92	2.34	0.35			
91	1994	31.22	3.29	1.03	28.83	2.72	0.78	19.86	2.21	0.44			
92	1994	21.36	3.2	0.68	19.54	3.32	0.65	13.62	2.23	0.3			
93	1994	15.17	3.64	0.55	14.18	3.45	0.49	9.14	3.46	0.32			

PEPs	inv	$\bar{D}$	Deviation		$\bar{H}$	Deviation		$\bar{H}_{CB}$	Deviation		$\bar{CW}$	Deviation	
			%	cm		%	m		%	m		%	m
94	1994	23.93	2.84	0.68	20.23	3.02	0.61	13.6	1.97	0.27			
95	1994	20.84	3.19	0.67	18.22	3.22	0.59	12.7	2.63	0.33			
96	1994	13.68	4.69	0.64	14.4	4.18	0.6	10.2	3.8	0.39			
201	1994	5.25	2.2	0.12	4.16	4.03	0.17						
206	1994	1.42	5.04	0.07	1.33	4.18	0.06						
Average value			3.3	0.6		3.08	0.51		2.37	0.32			
Minimum value			2.2	0.07		1.69	0.06		1.49	0.23			
Maximum value			5.04	1.03		4.18	0.78		3.8	0.51			
81	1998	28.33	3.64	1.03	24.8	3.13	0.78	16.56	3.31	0.55			
82	1998	22.95	4.62	1.06	20.64	3.36	0.69	12.93	2.33	0.3			
83	1998	29.69	2.29	0.68	27.23	1.69	0.46	20.49	1.61	0.33			
84	1998	24.08	2.75	0.66	23.32	1.78	0.41	15.93	1.77	0.28			
85	1998	24.51	2.62	0.64	23.46	1.86	0.44	17.2	2.07	0.36			
86	1998	16.24	3.22	0.52	16.28	3.65	0.59	11.57	2.74	0.32			
87	1998	18.78	3.64	0.68	18.51	3.52	0.65	13.6	2.66	0.36			
88	1998	15.52	3.41	0.53	17.33	3.15	0.55	12.85	2.65	0.34			
89	1998	19.07	3	0.57	19.36	2.38	0.46	14.27	2.17	0.31			
90	1998	24.02	2.87	0.69	22.32	2.7	0.6	15.74	2.57	0.41			
91	1998	32.12	3.25	1.04	29.36	2.51	0.74	20.67	2.45	0.51			
92	1998	22.45	3.28	0.74	20.7	3.29	0.68	13.95	2.19	0.31			
93	1998	16.68	3.59	0.6	15.84	3.5	0.55	9.72	3.09	0.3			
94	1998	25.01	2.82	0.7	21.11	2.79	0.59	14	1.93	0.27			
95	1998	22.17	3.27	0.73	18.8	3.21	0.6	12.98	2.84	0.37			
96	1998	15.44	5.09	0.79	15.74	4.62	0.73	10.79	3.54	0.38			
201	1998	8.78	2.03	0.18	7.77	2.34	0.18						
206	1998	4.88	3.3	0.16	3.13	7.67	0.24						
Average value			3.26	0.67		3.18	0.55		2.5	0.36			
Minimum value			2.03	0.16		1.69	0.18		1.61	0.27			
Maximum value			5.09	1.06		7.67	0.78		3.54	0.55			
81	2004	29.85	3.66	1.09	25.37	3.35	0.85	16.98	3.14	0.53			
82	2004	22.95	4.62	1.06	20.64	3.36	0.69	12.93	2.33	0.3			
83	2004	31.54	2.38	0.75	28.65	1.89	0.54	21.63	2	0.43			
84	2004	24.08	2.75	0.66	23.32	1.78	0.41	15.93	1.77	0.28			
85	2004	25.66	2.87	0.74	24.25	1.87	0.45	17.98	2.29	0.41			
86	2004	17.92	3.45	0.62	17.87	3.73	0.67	12.53	2.84	0.36			
87	2004	20.09	3.7	0.74	19.82	3.28	0.65	14.42	2.51	0.36			
88	2004	17.25	3.53	0.61	19.13	3.18	0.61	13.81	2.29	0.32			
89	2004	20.82	3.17	0.66	21.1	2.63	0.55	15.09	2.32	0.35			
90	2004	24.89	2.97	0.74	23.4	2.67	0.62	16.37	2.67	0.44			
91	2004	33.38	3.33	1.11	30.47	2.59	0.79	21.34	2.65	0.57			
92	2004	23.66	3.32	0.78	21.54	3.08	0.66	14.76	2.58	0.38			
93	2004	18.4	3.61	0.66	17.05	3.22	0.55	10.89	3.5	0.38			
94	2004	26.22	2.94	0.77	22	2.84	0.62	14.91	2.73	0.41			
95	2004	24.46	3.27	0.8	19.64	3.21	0.63	13.82	3.25	0.45			
96	2004	17.69	5.39	0.95	17.84	4.66	0.83	12.27	4.16	0.51			
201	2004	11.08	1.93	0.21	11.01	1.88	0.21						
206	2004	7.12	3.12	0.22	5.92	5.23	0.31						
Average value			3.33	0.73		3.02	0.59		2.69	0.4			
Minimum value			1.93	0.21		1.78	0.21		1.77	0.28			
Maximum value			5.39	1.11		5.23	0.85		4.16	0.57			
81	2009												
82	2009	26.58	6.13	1.63	22.11	3.21	0.71	14.59	3.24	0.47	3.47	9.75	0.34
83	2009	34.33	2.38	0.82	29.7	1.37	0.41	22.74	1.36	0.31	4.41	4.46	0.2
84	2009	27.98	2.9	0.81	25.73	1.49	0.38	18.29	1.38	0.25	3.64	4.17	0.15
85	2009	27.46	3.06	0.84	25.52	1.49	0.38	18.87	1.46	0.28	3.42	4.78	0.16
86	2009	20.13	3.64	0.73	20.15	2.25	0.45	14.35	1.81	0.26	2.85	5.46	0.16
87	2009	22.34	3.78	0.84	22.31	1.93	0.43	16.31	1.62	0.26	3.21	4.58	0.15

PEPs	inv	$\bar{D}$	Deviation		$\bar{H}$	Deviation		$\bar{H}_{CB}$	Deviation		$\bar{CW}$	Deviation	
			%	cm		%	m		%	m		%	m
88	2009	19.57	3.68	0.72	22.21	2.54	0.57	16.32	1.84	0.3	2.55	8.23	0.21
89	2009	22.84	3.15	0.72	23.52	1.6	0.38	17.44	1.5	0.26	2.76	5.08	0.14
90	2009	27.73	2.7	0.75	24.99	2.11	0.53	18.24	2.28	0.42	3.62	6.5	0.24
91	2009	34.96	3.32	1.16	30.84	2.35	0.72	21.95	2.72	0.6	4.57	8.11	0.37
92	2009	25.58	3.3	0.84	22.67	1.85	0.42	16.13	1.77	0.28	3.24	4.85	0.16
93	2009	20.29	3.55	0.72	18.62	1.8	0.34	13.1	1.64	0.21	3.06	5.16	0.16
94	2009	28.07	2.94	0.83	23.07	1.53	0.35	16.03	1.47	0.24	3.99	4.46	0.18
95	2009	26.41	3.32	0.88	21.18	1.66	0.35	14.82	1.77	0.26	4.03	4.79	0.19
96	2009	20.47	5.19	1.06	19.89	2.46	0.49	14.3	2.19	0.31	2.63	6.59	0.17
201	2009	13.23	1.9	0.25	13.6	1.75	0.24	9.39	1.53	0.14	1.98	5.62	0.11
206	2009	9.11	3.08	0.28	9.12	4.24	0.39	4.72	4.07	0.19	2.19	6.43	0.14
Average value			3.41	0.82		2.1	0.44		1.98	0.3		5.82	0.19
Minimum value			1.9	0.25		1.37	0.24		1.36	0.14		4.17	0.11
Maximum value			6.13	1.63		4.24	0.72		4.07	0.6		9.75	0.37

Appendix 2: Results of standard analysis of permanent experimental and validation plots.

			Growing stand											Removed stand						Total stand	
PEPs	inv	MSA	Sp	N	H_{AB}	D_{AB}	H_{100}	D_{100}	H_q	D_q	$\frac{H_q}{D_q}$	BA	V	$N_{removed}$	H_q removed	D_q removed	$\frac{H_q}{D_q}$	$BA_{removed}$	$V_{removed}$	GY	PAI_v
				trees ha^{-1}	m	cm	m	cm	m	cm		m^2 ha^{-1}	m^3 ha^{-1}	trees ha^{-1}	m	cm		m^2 ha^{-1}	m^3 ha^{-1}	m^3 ha^{-1}	m^3 ha^{-1}
81	1983	75	Pine	474	25.9	30.3	25.9	34.9	23.0	25.4	0.91	23.9	262.3	28	17.9	16.1	1.11	0.6	5.2	262.3	
			Spruce	9					9.5	11.1		0.1	0.6	0	0.0	0.0		0.0	0.0		
81	1989	81	Pine	448	25.8	30.9	26.5	36.9	23.7	27.2	0.87	26.0	292.1	26	20.2	19.6	1.03	0.8	7.8	299.9	6.3
			Spruce	9					12.9	14.3		0.1	1.0	0	0.0	0.0		0.0	0.0		
81	1993	85	Pine	437	25.8	30.7	26.8	37.5	24.2	27.9	0.87	26.8	305.9	11	24.8	29.6	0.84	0.8	9.2	322.9	5.7
			Spruce	2					12.4	13.8		0.0	0.1	0	0.0	0.0		0.0	0.0		
			Spruce	11					13.7	15.2		0.2	1.4	0	0.0	0.0		0.0	0.0		
81	1999	91	Pine	413	25.9	31.0	27.5	38.8	25.1	29.4	0.85	28.0	328.6	24	21.9	21.8	1.00	0.9	9.7	355.3	5.4
			Spruce	2					15.7	17.4		0.0	0.3	0	0.0	0.0		0.0	0.0		
			Spruce	11					12.0	13.4		0.2	1.1	7	13.3	14.7		0.1	0.8		
			Birch	2					11.3	9.3		0.0	0.1	0	0.0	0.0		0.0	0.0		
			Oak	9					3.8	4.2		0.1	0.4	0	0.0	0.0		0.0	0.0		
81	2005	97	Pine	359	26.0	31.4	27.9	39.6	25.7	30.8	0.83	26.8	322.6	54	23.7	25.1	0.95	2.7	30.3	379.6	4.0
			Spruce	2					16.8	18.8		0.1	0.3	0	0.0	0.0		0.0	0.0		
			Spruce	2					8.4	10.2		0.0	0.1	9	12.6	14.0		0.1	1.0		
			Oak	6					10.3	12.4		0.1	0.3	4	8.5	9.3		0.0	0.1		
82	1983	31	Pine	980	33.3	42.3	17.6	24.4	16.1	17.1	0.94	22.6	180.3	520	13.2	10.3	1.29	4.3	30.4	180.3	
			Birch	20					17.6	15.7		0.4	3.0	0	0.0	0.0		0.0	0.0		
82	1989	37	Pine	724	31.9	40.7	19.7	26.7	17.9	19.5	0.92	21.6	188.0	256	15.9	14.7	1.08	4.3	33.7	221.8	6.9
			Birch	20					19.0	17.8		0.5	4.4	0	0.0	0.0		0.0	0.0		
82	1994	42	Pine	628	31.6	39.9	22.0	29.3	19.5	21.4	0.91	22.6	213.7	96	18.1	18.2	0.99	2.5	21.6	269.0	9.5
			Birch	20					19.8	19.1		0.6	5.4	0	0.0	0.0		0.0	0.0		
82	1999	47	Pine	436	31.4	40.0	23.2	30.5	21.1	23.6	0.89	19.1	193.0	192	18.8	18.7	1.01	5.2	47.5	295.7	5.3
			Birch	16					20.5	20.3		0.5	4.9	4	20.6	20.5		0.1	1.2		
			Spruce	4					4.2	6.7		0.0	0.0	0	0.0	0.0		0.0	0.0		
82	2005	53	Pine	436	29.0	36.4	23.2	30.5	21.1	23.6	0.89	19.1	193.0	0	0.0	0.0		0.0	0.0	295.7	0.0
			Birch	16					20.5	20.3		0.5	4.9	0	0.0	0.0		0.0	0.0		
			Spruce	4					4.2	6.7		0.0	0.0	0	0.0	0.0		0.0	0.0		
82	2010	58	Pine	268	29.7	39.1	24.5	33.6	22.9	27.4	0.84	15.8	170.2	168	21.4	23.1	0.93	7.1	70.8	343.8	4.4
			Birch	8					23.3	27.1		0.5	4.5	8	19.3	18.3		0.2	2.0		

			Growing stand											Removed stand						Total stand	
PEPs	inv	MSA	Sp	N	H_{AB}	D_{AB}	H_{100}	D_{100}	H_q	D_q	$\frac{H_q}{D_q}$	BA	V	$N_{removed}$	H_q removed	D_q removed	$\frac{H_q}{D_q}$	$BA_{removed}$	$V_{removed}$	GY	PAI_v
				trees ha^{-1}	m	cm	m	cm	m	cm		m^2 ha^{-1}	m^3 ha^{-1}	trees ha^{-1}	m	cm		m^2 ha^{-1}	m^3 ha^{-1}	m^3 ha^{-1}	m^3 ha^{-1}
			Spruce	76					8.3	10.2		0.6	3.1	0	0.0	0.0		0.0	0.0		
			Birch	52					7.8	6.8		0.2	0.8	0	0.0	0.0		0.0	0.0		
			Aspen	24					6.6	6.4		0.1	0.3	0	0.0	0.0		0.0	0.0		
83	1983	61	Pine	589	30.8	36.3	26.1	34.5	24.6	26.3	0.93	32.1	368.7	16	21.8	17.9	1.22	0.4	4.1	368.7	
			Birch	3					22.7	25.2		0.2	1.6	0	0.0	0.0		0.0	0.0		
			Spruce	2					13.4	14.8		0.0	0.2	0	0.0	0.0		0.0	0.0		
83	1989	67	Pine	539	30.4	35.9	27.0	36.1	25.6	27.9	0.92	33.0	392.4	50	23.4	20.5	1.14	1.7	18.0	410.4	7.0
			Birch	3					23.0	26.1		0.2	1.7	0	0.0	0.0		0.0	0.0		
			Spruce	2					16.2	18.0		0.0	0.3	0	0.0	0.0		0.0	0.0		
83	1993	71	Pine	527	30.6	35.6	28.0	37.2	26.5	28.8	0.92	34.3	420.9	13	24.4	21.6	1.13	0.5	5.1	444.0	8.4
			Birch	3					23.3	27.0		0.2	1.9	0	0.0	0.0		0.0	0.0		
			Spruce	14					9.7	11.3		0.1	0.8	0	0.0	0.0		0.0	0.0		
			Oak	8					9.9	11.6		0.1	0.4	0	0.0	0.0		0.0	0.0		
83	1999	77	Pine	498	30.5	35.5	29.0	38.9	27.5	30.3	0.91	36.0	456.1	28	25.2	22.2	1.13	1.1	12.7	491.8	8.0
			Birch	2					24.3	30.0		0.1	1.3	2	22.4	24.4		0.1	0.7		
			Spruce	36					9.6	11.3		0.4	1.9	0	0.0	0.0		0.0	0.0		
			Birch	3					8.2	7.1		0.0	0.1	0	0.0	0.0		0.0	0.0		
			Oak	122					1.3	1.1		1.0	5.0	0	0.0	0.0		0.0	0.0		
			Maple	2					11.4	12.9		0.0	0.1	0	0.0	0.0		0.0	0.0		
			Pear	5					10.5	11.3		0.0	0.2	0	0.0	0.0		0.0	0.0		
83	2005	83	Pine	458	31.1	35.9	30.7	40.9	29.0	32.2	0.90	37.3	496.7	41	26.6	24.1	1.10	1.9	22.6	555.1	10.5
			Birch	2					24.3	30.0		0.1	1.3	0	0.0	0.0		0.0	0.0		
			Spruce	48					11.8	13.3		0.7	4.2	0	0.0	0.0		0.0	0.0		
			Birch	5					8.6	7.4		0.0	0.1	0	0.0	0.0		0.0	0.0		
			Oak	131					10.1	11.9		1.5	7.9	0	0.0	0.0		0.0	0.0		
			Maple	2					13.7	19.0		0.0	0.3	0	0.0	0.0		0.0	0.0		
			Pear	5					12.0	14.2		0.1	0.4	0	0.0	0.0		0.0	0.0		
83	2010	88	Pine	409	31.5	37.6	32.1	43.6	30.1	35.0	0.86	39.3	540.0	48	26.8	25.5	1.05	2.5	31.3	629.7	14.9
			Birch	0					0.0	0.0		0.0	0.0	2	24.3	30.0		0.1	1.3		
			Spruce	0					0.0	0.0		0.0	0.0	0	0.0	0.0		0.0	0.0		
			Spruce	70					13.0	14.4		1.2	7.9	0	0.0	0.0		0.0	0.0		
			Birch	6					9.5	8.0		0.0	0.1	3	8.6	7.4		0.0	0.1		

			Growing stand											Removed stand						Total stand	
PEPs	inv	MSA	Sp	N	H_{AB}	D_{AB}	H_{100}	D_{100}	H_q	D_q	$\frac{H_q}{D_q}$	BA	V	$N_{removed}$	H_q removed	D_q removed	$\frac{H_q}{D_q}$	$BA_{removed}$	$V_{removed}$	GY	PAI_v
				trees ha^{-1}	m	cm	m	cm	m	cm		m^2 ha^{-1}	m^3 ha^{-1}	trees ha^{-1}	m	cm		m^2 ha^{-1}	m^3 ha^{-1}	m^3 ha^{-1}	m^3 ha^{-1}
			Oak	150					10.5	12.8		1.9	11.1	5	7.2	7.5		0.0	0.1		
			Maple	2					14.7	23.1		0.1	0.6	0	0.0	0.0		0.0	0.0		
			Pear	8					11.8	13.7		0.1	0.7	0	0.0	0.0		0.0	0.0		
84	1983	40	Pine	995	33.1	37.1	21.6	26.7	19.8	18.9	1.05	27.9	267.2	307	16.4	11.7	1.41	3.3	27.7	267.2	
84	1989	46	Pine	679	32.8	37.7	23.1	29.1	21.7	21.8	1.00	25.3	262.0	317	19.6	15.4	1.27	5.9	54.1	316.2	8.2
84	1994	51	Pine	624	31.8	36.6	24.3	30.5	22.6	23.0	0.98	26.0	279.1	55	21.3	19.1	1.12	1.6	15.8	349.1	6.6
			Spruce	5					7.1	9.2		0.0	0.1	0	0.0	0.0		0.0	0.0		
84	1999	56	Pine	555	31.1	36.3	25.3	32.0	23.5	24.6	0.96	26.4	293.3	69	21.0	18.0	1.17	1.8	17.9	381.2	6.4
			Spruce	12					8.7	10.5		0.1	0.4	0	0.0	0.0		0.0	0.0		
84	2005	62	Pine	555	29.3	33.7	25.3	32.0	23.5	24.6	0.96	26.4	293.3	0	0.0	0.0		0.0	0.0	381.2	0.0
			Spruce	12					8.7	10.5		0.1	0.4	0	0.0	0.0		0.0	0.0		
84	2010	67	Pine	505	31.2	36.8	28.3	36.7	26.2	28.6	0.92	32.5	396.3	50	21.9	18.8	1.16	1.4	14.5	498.7	10.7
			Spruce	21					14.2	15.7		0.4	2.6	0	0.0	0.0		0.0	0.0		
85	1984	50	Pine	948	28.9	32.9	22.1	29.0	20.2	20.2	1.00	30.5	297.0	186	16.5	12.2	1.35	2.2	18.6	297.0	
			Birch	14					17.0	14.9		0.3	2.1	0	0.0	0.0		0.0	0.0		
			Spruce	2					16.4	18.2		0.1	0.6	0	0.0	0.0		0.0	0.0		
85	1989	55	Pine	821	28.6	33.0	23.1	30.7	21.3	22.0	0.97	31.2	317.2	126	18.4	14.6	1.26	2.1	18.8	336.1	7.8
			Birch	12					18.6	17.1		0.3	2.4	2	9.1	7.7		0.0	0.1		
			Spruce	2					17.9	20.2		0.1	0.7	0	0.0	0.0		0.0	0.0		
85	1994	60	Pine	798	28.7	32.7	24.6	32.7	22.5	23.3	0.97	34.0	364.3	24	20.7	18.2	1.14	0.6	6.1	389.2	10.6
			Birch	12					19.3	18.2		0.3	2.8	0	0.0	0.0		0.0	0.0		
			Spruce	2					18.8	21.5		0.1	0.9	0	0.0	0.0		0.0	0.0		
85	1999	65	Pine	650	29.2	33.1	25.8	33.7	24.1	25.1	0.96	32.2	363.9	148	21.5	17.6	1.22	3.6	35.5	424.4	7.0
			Birch	10					19.4	18.4		0.3	2.4	2	20.2	19.8		0.1	0.7		
85	2004	70	Pine	562	28.9	32.9	26.7	35.1	24.8	26.3	0.94	30.5	355.6	88	24.4	24.8	0.98	4.3	48.1	464.1	7.9
			Birch	10					19.6	18.8		0.3	2.6	0	0.0	0.0		0.0	0.0		
85	2010	76	Pine	507	29.0	33.3	28.0	37.2	26.0	28.2	0.92	31.6	382.5	55	24.3	23.1	1.05	2.3	26.3	517.4	8.9
			Birch	7					20.9	21.2		0.3	2.6	2	15.0	12.6		0.0	0.2		
86	1984	48	Pine	2324	19.6	21.6	15.3	21.9	12.8	12.2	1.05	27.4	184.6	712	9.7	7.1	1.36	2.8	15.5	184.6	
			Birch	4					7.5	6.7		0.0	0.1	0	0.0	0.0		0.0	0.0		
86	1989	53	Pine	2072	19.8	21.9	16.7	24.0	13.9	13.6	1.02	30.3	218.5	252	10.4	7.9	1.32	1.2	7.1	225.6	8.2
			Birch	4					10.7	8.9		0.0	0.1	0	0.0	0.0		0.0	0.0		

			Growing stand										Removed stand						Total stand	
PEPs	inv	MSA	Sp	N	H_{AB}	D_{AB}	H_{100}	D_{100}	H_q	D_q	$\frac{H_q}{D_q}$	BA	V	$N_{removed}$	H_q removed	D_q removed	$\frac{H_q}{D_q}$	$BA_{removed}$	$V_{removed}$	GY	PAI_v
				trees ha^{-1}	m	cm	m	cm	m	cm		m^2 ha^{-1}	m^3 ha^{-1}	trees ha^{-1}	m	cm		m^2 ha^{-1}	m^3 ha^{-1}	m^3 ha^{-1}	m^3 ha^{-1}
86	1994	58	Pine	1832	20.6	22.5	18.7	26.2	15.5	15.2	1.02	33.2	262.7	240	12.4	9.9	1.24	1.9	12.2	282.0	11.3
			Birch	4					11.8	9.7		0.0	0.2	0	0.0	0.0		0.0	0.0		
86	1999	63	Pine	1380	21.4	23.4	20.0	27.4	17.0	17.0	1.00	31.2	265.7	456	13.4	10.8	1.24	4.2	29.1	314.1	6.4
			Birch	4					13.2	10.9		0.0	0.2	0	0.0	0.0		0.0	0.0		
86	2004	68	Pine	1212	22.2	24.3	21.7	29.5	18.6	18.7	0.99	33.4	306.1	168	14.7	12.0	1.22	1.9	14.1	368.6	10.9
			Birch	4					14.5	12.1		0.0	0.3	0	0.0	0.0		0.0	0.0		
86	2010	74	Pine	1020	23.7	25.5	23.6	31.9	20.8	21.0	0.99	35.3	355.7	192	17.7	14.5	1.22	3.2	26.6	444.9	12.7
			Birch	4					15.3	12.9		0.1	0.4	0	0.0	0.0		0.0	0.0		
87	1984	50	Pine	1544	23.0	25.5	18.8	26.6	15.8	15.3	1.03	28.6	229.0	524	11.5	8.6	1.33	3.0	19.3	229.0	
			Birch	16					13.9	11.5		0.2	1.0	0	0.0	0.0		0.0	0.0		
			Spruce	8					11.7	13.1		0.1	0.7	0	0.0	0.0		0.0	0.0		
87	1989	55	Pine	1312	23.5	26.0	20.4	28.2	17.3	17.0	1.01	29.9	257.9	232	13.3	10.4	1.27	2.0	13.7	271.6	8.5
			Birch	12					16.2	13.9		0.2	1.3	4	7.1	6.4		0.0	0.0		
			Spruce	8					12.9	14.3		0.1	0.9	0	0.0	0.0		0.0	0.0		
87	1994	60	Pine	1260	23.8	25.9	21.7	30.0	18.5	18.2	1.01	32.9	301.4	52	13.4	10.0	1.33	0.4	2.8	317.9	9.3
			Birch	12					17.2	15.1		0.2	1.7	0	0.0	0.0		0.0	0.0		
			Spruce	8					14.2	15.7		0.2	1.2	0	0.0	0.0		0.0	0.0		
87	1999	65	Pine	1080	24.2	26.2	22.9	30.7	19.8	19.6	1.01	32.7	315.9	180	15.4	12.1	1.28	2.1	15.9	348.4	6.1
			Birch	8					19.2	18.0		0.2	1.7	4	10.3	8.6		0.0	0.1		
87	2004	70	Pine	984	24.6	26.4	23.8	31.9	21.0	20.9	1.00	33.9	344.0	96	17.2	13.6	1.26	1.4	11.7	388.1	7.9
			Birch	8					20.2	19.8		0.2	2.3	0	0.0	0.0		0.0	0.0		
87	2010	76	Pine	800	25.8	27.5	25.8	33.3	23.0	23.2	1.00	33.7	369.8	184	20.0	16.6	1.20	4.0	37.7	451.6	10.6
			Birch	4					23.2	26.8		0.2	2.2	4	15.8	13.5		0.1	0.5		
88	1984	29	Pine	3035	29.7	30.5	14.9	18.8	13.3	10.9	1.22	28.5	199.0	476	11.7	7.3	1.60	2.0	13.0	199.0	
			Birch	6					9.2	7.8		0.0	0.2	0	0.0	0.0		0.0	0.0		
88	1989	34	Pine	2706	28.8	29.6	16.4	21.6	14.8	12.5	1.19	33.2	252.1	329	12.2	7.0	1.76	1.3	7.9	260.0	12.2
88	1994	39	Pine	2494	28.4	29.1	18.7	24.4	16.4	14.1	1.17	38.7	321.2	212	12.9	8.0	1.62	1.1	7.5	336.6	15.3
88	1999	44	Pine	1782	28.4	29.8	20.2	25.4	18.0	16.2	1.11	36.8	329.2	712	14.4	9.4	1.53	5.0	37.0	381.7	9.0
88	2004	49	Pine	1565	29.1	30.0	22.7	27.4	20.0	18.0	1.11	39.7	390.1	218	15.1	10.0	1.50	1.7	13.4	456.0	14.9
88	2010	55	Pine	1300	30.7	30.7	25.8	29.8	22.9	20.3	1.13	42.1	465.0	265	17.9	12.1	1.48	3.0	26.0	556.9	16.8
89	1984	39	Pine	1644	26.9	29.8	17.2	22.4	15.4	14.5	1.07	27.0	210.5	304	13.0	9.4	1.39	2.1	14.6	210.5	
89	1989	44	Pine	1400	26.8	30.2	18.6	24.7	16.9	16.4	1.03	29.7	249.2	244	14.4	10.5	1.37	2.1	15.3	264.5	10.8

			Growing stand											Removed stand						Total stand	
PEPs	inv	MSA	Sp	N trees ha^{-1}	H_{AB} m	D_{AB} cm	H_{100} m	D_{100} cm	H_q m	D_q cm	$\frac{H_q}{D_q}$	BA m^2 ha^{-1}	V m^3 ha^{-1}	$N_{removed}$ trees ha^{-1}	H_q removed m	D_q removed cm	$\frac{H_q}{D_q}$	$BA_{removed}$ m^2 ha^{-1}	$V_{removed}$ m^3 ha^{-1}	GY m^3 ha^{-1}	PAI_v m^3 ha^{-1}
89	1994	49	Pine	1328	26.8	30.1	20.5	26.9	18.3	18.0	1.02	33.9	305.1	72	14.3	10.3	1.39	0.6	4.5	324.8	12.1
89	1999	54	Pine	1100	27.3	30.2	22.1	28.2	20.0	19.7	1.02	33.4	324.1	228	16.9	12.9	1.31	3.0	24.3	368.2	8.7
89	2004	59	Pine	1000	28.1	30.7	24.2	30.7	21.8	21.5	1.02	36.3	379.8	100	18.3	14.2	1.29	1.6	14.0	437.9	13.9
89	2010	65	Pine	888	29.4	31.1	26.5	32.3	24.2	23.5	1.03	38.5	440.5	112	20.4	15.5	1.32	2.1	19.9	518.4	13.4
90	1984	66	Pine	812	24.2	27.3	22.4	28.6	20.0	20.7	0.96	27.4	264.9	0	0.0	0.0	0.0	0.0	0.0	264.9	
			Birch	2					24.3	30.0		0.2	1.7	0	0.0	0.0		0.0	0.0		
90	1989	71	Pine	776	24.1	27.2	23.2	30.1	20.7	21.8	0.95	28.9	288.5	36	18.0	16.2	1.11	0.7	6.6	295.1	6.0
			Birch	2					24.9	32.3		0.2	2.0	0	0.0	0.0		0.0	0.0		
90	1994	76	Pine	650	24.8	28.1	24.3	31.9	22.1	23.7	0.93	28.7	301.5	126	20.0	18.4	1.08	3.4	31.7	339.9	8.9
			Birch	2					25.3	34.0		0.2	2.4	0	0.0	0.0		0.0	0.0		
90	1999	81	Pine	629	25.0	28.1	24.9	33.1	22.9	24.7	0.93	30.1	326.1	21	21.5	20.6	1.04	0.7	7.1	371.5	6.3
			Birch	2					25.7	35.9		0.2	2.8	0	0.0	0.0		0.0	0.0		
90	2005	87	Pine	619	25.4	27.8	25.9	34.6	24.1	25.6	0.94	31.9	360.9	10	23.4	23.3	1.00	0.4	4.4	410.7	6.5
			Birch	2					26.0	37.2		0.3	3.1	0	0.0	0.0		0.0	0.0		
90	2009	91	Pine	510	26.5	29.9	27.6	36.1	25.6	28.3	0.90	32.0	381.6	110	21.3	18.6	1.14	3.0	31.0	462.4	12.9
91	1985	72	Pine	418	31.9	36.0	29.8	38.1	27.9	29.4	0.95	28.4	366.9	39	22.1	16.6	1.33	0.8	9.1	366.9	
			Spruce	14					23.0	29.4		0.9	10.5	0	0.0	0.0		0.0	0.0		
			Spruce	102					8.1	9.9		0.8	4.5	0	0.0	0.0		0.0	0.0		
			Oak	4					8.3	9.0		0.0	0.1	0	0.0	0.0		0.0	0.0		
91	1989	76	Pine	375	31.7	36.4	30.2	39.0	28.4	30.8	0.92	28.0	366.4	43	26.3	24.4	1.08	2.0	24.9	391.4	6.1
			Spruce	14					23.8	31.2		1.0	12.1	0	0.0	0.0		0.0	0.0		
			Spruce	98					9.8	11.4		1.0	6.1	4	8.0	9.9		0.0	0.2		
			Oak	4					9.6	11.0		0.0	0.2	0	0.0	0.0		0.0	0.0		
91	1994	81	Pine	361	31.4	36.2	30.8	40.5	29.0	32.0	0.91	29.0	387.0	14	29.3	33.5	0.88	1.2	16.3	428.2	7.4
			Spruce	14					24.4	32.9		1.2	13.8	0	0.0	0.0		0.0	0.0		
			Spruce	216					9.3	10.9		2.0	11.8	2	9.9	11.5		0.0	0.1		
			Oak	10					9.3	10.4		0.1	0.4	0	0.0	0.0		0.0	0.0		
91	1999	86	Pine	353	31.2	35.9	31.3	41.3	29.6	32.9	0.90	30.0	406.7	8	26.2	23.0	1.14	0.3	4.4	452.3	4.8
			Spruce	14					24.9	34.3		1.3	15.4	0	0.0	0.0		0.0	0.0		
			Spruce	325					9.8	11.4		3.3	20.5	4	11.7	13.1		0.1	0.3		
			Oak	18					0.0	0.0		0.1	0.8	0	0.0	0.0		0.0	0.0		
91	2005	92	Pine	351	31.1	35.8	32.2	43.0	30.2	34.2	0.88	32.3	453.1	2	25.5	22.1	1.15	0.1	0.9	499.7	7.9

			Growing stand											Removed stand						Total stand	
PEPs	inv	MSA	Sp	N	H_{AB}	D_{AB}	H_{100}	D_{100}	H_q	D_q	$\frac{H_q}{D_q}$	BA	V	$N_{removed}$	$H_{q\,removed}$	$D_{q\,removed}$	$\frac{H_q}{D_q}$	$BA_{removed}$	$V_{removed}$	GY	PAI_v
				trees ha^{-1}	m	cm	m	cm	m	cm		m^2 ha^{-1}	m^3 ha^{-1}	trees ha^{-1}	m	cm		m^2 ha^{-1}	m^3 ha^{-1}	m^3 ha^{-1}	m^3 ha^{-1}
			Spruce	14					25.7	36.4		1.4	17.9	0	0.0	0.0		0.0	0.0		
			Spruce	322					11.3	12.7		4.1	27.9	14	12.6	14.0		0.2	1.5		
			Oak	18					9.3	10.5		0.2	0.9	0	0.0	0.0		0.0	0.0		
91	2009	96	Pine	339	31.3	36.6	32.9	44.6	30.9	35.8	0.86	34.2	481.1	12	28.1	27.6	1.02	0.7	9.1	536.8	9.3
			Spruce	14					26.1	37.9		1.5	20.1	0	0.0	0.0		0.0	0.0		
			Spruce	314					12.7	14.1		4.9	36.3	8	12.4	13.8		0.1	0.8		
			Oak	14					9.4	10.6		0.1	0.8	4	9.7	11.2		0.0	0.2		
92	1985	60	Pine	1002	22.8	26.6	20.9	29.7	17.7	18.7	0.94	27.6	242.1	140	10.9	8.9	1.22	0.9	5.4	242.1	
			Birch	14					14.3	11.9		0.2	1.0	0	0.0	0.0		0.0	0.0		
92	1989	64	Pine	864	23.1	27.5	21.4	31.1	18.7	20.4	0.92	28.2	257.8	138	15.1	13.0	1.16	1.8	13.8	271.6	7.4
			Birch	12					15.0	12.6		0.1	1.0	2	10.9	9.0		0.0	0.1		
92	1994	69	Pine	738	23.9	28.3	22.7	32.4	20.2	22.2	0.91	28.6	278.9	126	16.7	14.6	1.15	2.1	17.1	309.9	7.6
			Birch	7					17.1	15.0		0.1	1.0	5	9.2	7.8		0.0	0.1		
92	1999	74	Pine	707	24.3	28.2	23.7	33.6	21.3	23.4	0.91	30.3	309.3	33	19.0	17.5	1.09	0.8	7.1	347.4	7.5
			Birch	5					17.2	15.2		0.1	0.7	2	17.0	14.9		0.0	0.3		
92	2005	80	Pine	650	24.2	28.2	24.3	34.7	22.1	24.6	0.90	30.8	323.8	57	18.4	15.6	1.18	1.1	9.8	371.6	4.0
			Birch	2					13.8	11.4		0.0	0.2	2	19.3	18.2		0.1	0.5		
92	2010	85	Pine	562	24.8	29.1	25.5	36.0	23.3	26.4	0.88	30.8	338.0	88	21.6	21.8	0.99	3.3	34.1	420.0	9.7
93	1985	38	Pine	1850	20.8	27.4	13.5	20.3	11.3	12.8	0.89	23.7	143.0	69	8.2	7.4	1.10	0.3	1.4	143.0	
93	1989	42	Pine	1650	21.4	27.4	14.6	21.8	12.7	14.1	0.90	25.8	169.8	200	9.6	8.0	1.20	1.0	5.1	174.9	8.0
93	1994	47	Pine	1506	22.1	27.6	16.4	23.7	14.4	15.8	0.91	29.5	215.0	144	9.3	7.4	1.26	0.6	3.2	223.4	9.7
93	1999	52	Pine	1350	22.9	27.6	18.3	25.4	16.1	17.3	0.93	31.6	254.1	156	12.3	10.0	1.22	1.2	7.7	270.1	9.3
93	2005	58	Pine	1150	22.7	27.6	19.3	27.0	17.2	19.0	0.91	32.5	274.1	200	13.4	11.6	1.16	2.1	15.0	305.1	5.8
93	2010	63	Pine	1031	23.8	28.4	20.9	28.7	19.1	20.8	0.92	35.1	323.9	119	16.4	14.3	1.15	1.9	14.5	369.5	12.9
94	1985	67	Pine	714	22.7	28.4	20.9	30.4	18.8	21.9	0.86	26.9	244.5	108	14.3	12.6	1.13	1.4	10.2	244.5	
			Birch	2					18.7	17.2		0.0	0.4	0	0.0	0.0		0.0	0.0		
94	1989	71	Pine	612	23.0	29.1	21.4	31.7	19.7	23.4	0.84	26.3	248.3	102	17.8	17.9	1.00	2.6	21.9	270.2	6.4
			Birch	2					18.8	17.4		0.0	0.4	0	0.0	0.0		0.0	0.0		
94	1994	76	Pine	584	23.6	29.2	23.1	32.8	21.0	24.6	0.85	27.8	278.5	29	16.2	14.4	1.12	0.5	3.8	304.3	6.8
			Birch	2					18.8	17.4		0.0	0.4	0	0.0	0.0		0.0	0.0		
94	1999	81	Pine	547	23.9	29.2	23.8	33.7	21.9	25.7	0.85	28.4	293.8	37	18.5	17.5	1.06	0.9	7.8	327.4	4.6
			Birch	2					19.2	18.0		0.1	0.5	0	0.0	0.0		0.0	0.0		

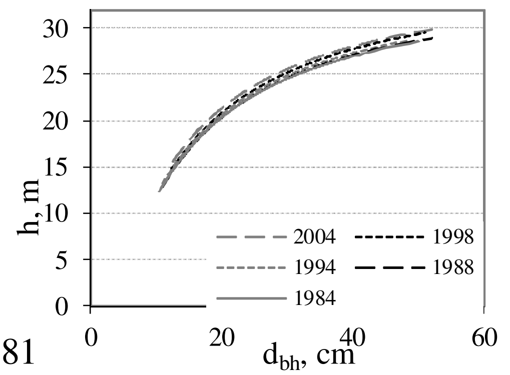
			Growing stand											Removed stand						Total stand	
PEPs	**inv**	**MSA**	**Sp**	**N** trees ha^{-1}	**H_{AB}** m	**D_{AB}** cm	**H_{100}** m	**D_{100}** cm	**H_q** m	**D_q** cm	**$\frac{H_q}{D_q}$**	**BA** m^2 ha^{-1}	**V** m^3 ha^{-1}	**$N_{removed}$** trees ha^{-1}	**H_q removed** m	**D_q removed** cm	**$\frac{H_q}{D_q}$**	**$BA_{removed}$** m^2 ha^{-1}	**$V_{removed}$** m^3 ha^{-1}	**GY** m^3 ha^{-1}	**PAI_v** m^3 ha^{-1}
94	2005	87	Pine	480	23.8	29.2	24.3	34.7	22.6	26.9	0.84	27.3	289.2	67	20.8	21.5	0.97	2.4	23.9	346.7	3.2
			Birch	2					19.2	18.0		0.1	0.5	0	0.0	0.0		0.0	0.0		
94	2011	93	Pine	459	24.3	30.0	25.4	36.8	23.6	28.8	0.82	29.9	329.5	20	21.2	21.9	0.97	0.8	7.8	394.8	8.0
			Birch	2					19.3	18.2		0.1	0.5	0	0.0	0.0		0.0	0.0		
95	1985	68	Pine	922	20.2	24.3	19.0	27.5	16.8	18.7	0.90	25.4	210.9	289	12.2	10.3	1.19	2.4	16.1	210.9	
			Birch	3					17.8	16.0		0.1	0.4	0	0.0	0.0		0.0	0.0		
95	1989	72	Pine	789	20.8	25.2	19.7	28.8	17.9	20.4	0.88	25.7	223.4	133	15.1	13.4	1.12	1.9	13.8	237.2	6.6
			Birch	3					17.8	16.0		0.1	0.4	0	0.0	0.0		0.0	0.0		
95	1994	77	Pine	728	21.1	25.4	20.8	30.0	18.9	21.5	0.87	26.5	241.9	61	16.4	15.5	1.06	1.1	9.5	265.2	5.6
			Birch	3					17.8	16.0		0.1	0.5	0	0.0	0.0		0.0	0.0		
95	1999	82	Pine	631	21.0	25.8	21.0	30.9	19.3	22.9	0.84	25.9	239.7	97	17.1	16.6	1.03	2.1	18.0	281.0	3.2
95	2005	88	Pine	475	21.1	27.0	21.5	32.1	20.0	25.0	0.80	23.4	222.6	156	17.8	18.3	0.97	4.1	35.8	299.7	3.1
			Birch	3					8.2	7.1		0.0	0.0	0	0.0	0.0		0.0	0.0		
95	2011	94	Pine	464	22.1	28.0	23.2	34.6	21.6	27.0	0.80	26.6	270.8	11	19.0	19.4	0.98	0.3	2.9	350.7	8.5
			Birch	8					8.7	7.4		0.0	0.2	0	0.0	0.0		0.0	0.0		
96	1985	44	Pine	2865	19.4	21.1	14.6	20.0	11.8	11.0	1.08	27.1	172.6	635	8.5	6.4	1.33	2.0	10.4	172.6	
96	1989	48	Pine	2344	20.0	21.9	15.6	22.0	13.1	12.5	1.05	28.7	196.8	521	9.3	6.7	1.39	1.8	9.5	206.3	8.4
96	1994	53	Pine	1948	21.0	23.0	17.5	24.0	14.9	14.4	1.03	31.7	241.0	396	10.5	7.6	1.38	1.8	10.2	260.7	10.9
96	1999	58	Pine	1469	21.7	23.8	18.9	25.2	16.4	16.1	1.02	30.1	248.0	479	14.4	11.9	1.21	5.4	40.3	308.0	9.5
96	2005	64	Pine	1167	22.8	25.0	20.5	27.4	18.4	18.4	1.00	31.1	280.4	313	14.9	11.0	1.35	3.0	20.3	360.7	8.8
96	2010	69	Pine	979	24.2	26.9	22.6	30.1	20.5	21.1	0.97	34.3	338.2	198	15.9	11.9	1.33	2.2	17.4	435.8	15.0
201	1990	8	Pine	5403	25.6	40.4	2.9	5.3	2.2	2.5	0.86	2.7	6.6	0	0.0	0.0	0.0	0.0	0.0	6.6	
201	1995	13	Pine	4744	25.8	40.2	5.4	10.9	4.6	5.8	0.80	12.5	38.2	664	1.4	0.7	1.98	0.0	0.2	38.4	6.4
201	2001	19	Pine	3894	27.9	40.0	9.0	16.2	8.1	9.4	0.86	27.1	123.0	853	4.0	2.2	1.78	0.3	1.0	124.2	14.3
201	2006	24	Pine	3247	30.2	38.3	12.4	19.3	11.4	11.7	0.97	34.9	208.3	647	8.0	4.3	1.85	0.9	3.7	213.2	17.8
201	2011	29	Pine	2647	31.2	37.1	15.4	22.0	14.1	13.8	1.02	39.7	284.7	600	11.1	6.8	1.64	2.2	12.0	301.6	17.7
206	1996	7	Pine	4906	28.3	40.5	2.8	4.3	2.0	1.9	1.10	1.3	3.8	3004	1.3	0.3	5.15	0.0	0.0	3.8	
206	2001	12	Pine	4507	25.7	42.2	5.5	10.7	4.1	5.5	0.75	10.8	31.7	422	1.3	0.7	1.88	0.0	0.1	31.9	5.6
206	2006	17	Pine	4139	25.7	38.8	7.6	14.6	6.4	7.9	0.81	20.3	78.4	368	2.4	1.8	1.35	0.1	0.3	78.9	9.4
206	2011	22	Pine	3565	28.9	36.4	11.6	17.7	9.9	10.0	0.99	27.8	151.5	565	5.6	3.8	1.47	0.6	2.2	154.2	15.1
5	1983	34	Pine	2064	25.3	28.9	15.0	18.5	12.8	12.2	1.05	24.0	161.4	0	0.0	0.0	0.0	0.0	0.0	161.4	
			Spruce	32			15.2	12.5	15.2	12.5		0.4	3.4	0	0.0	0.0		0.0	0.0		

			Growing stand											Removed stand						Total stand	
PEPs	**inv**	**MSA**	**Sp**	**N**	**H_{AB}**	**D_{AB}**	**H_{100}**	**D_{100}**	**H_q**	**D_q**	**$\frac{H_q}{D_q}$**	**BA**	**V**	**$N_{removed}$**	**H_q removed**	**D_q removed**	**$\frac{H_q}{D_q}$**	**$BA_{removed}$**	**$V_{removed}$**	**GY**	**PAI_v**
				trees ha^{-1}	**m**	**cm**	**m**	**cm**	**m**	**cm**		**m^2 ha^{-1}**	**m^3 ha^{-1}**	**trees ha^{-1}**	**m**	**cm**		**m^2 ha^{-1}**	**m^3 ha^{-1}**	**m^3 ha^{-1}**	**m^3 ha^{-1}**
5	1985	36	pine	2040	25,5	29,1	15.9	19.9	13.6	13.0	1.0	27.2	191.5	24.0	10.9	8.6	1.3	0.1	0.8	192.4	15.5
			spruce	32			16.4	13.3	16.4	13.3	1.2	0.4	4.1	0.0				0.0	0.0		
5	1996	47	pine	1460	24,5	29,6	17.9	25.9	16.1	17.0	0.9	33.3	267.0	580.0	14.3	12.1	1.2	6.6	45.8	313.6	11.0
			spruce	24			22.0	18.1	22.0	18.1	1.2	0.6	7.3	8.0	13.2	11.1	1.2	0.1	0.6		
5	2008	59	Pine	980	28.4	30.8	24.3	29.9	22.1	21.6	1.03	35.8	378.3	480	17.5	12.6	1.39	6.0	44.8	469.7	13.0
			Spruce	20					23.9	20.1		0.6	8.1	0	0	0		0	0		
7	1983	60	Pine	588	28.5	31.2	24.7	30.5	22.4	22.2	1.01	22.7	243.6	0	0.0	0.0	0.0	0.0	0.0	243.6	
			Birch	55					21.0	19.2		1.6	15.6	0	0.0	0.0		0.0	0.0		
			Spruce	223					18.3	16.4		4.7	46.1	0	0.0	0.0		0.0	0.0		
			Spruce	923					11.0	8.9		5.8	39.0	0	0.0	0.0		0.0	0.0		
			Birch	13					15.1	11.8		0.14	1.0	0	0.0	0.0		0.0	0.0		
7	2012	89	Pine	435	29.0	32.8	30.0	40.2	27.8	30.7	0.9	32.2	415.5	153	22.5	18.7	1.2	4.2	43.6	459.1	7.4
			Birch	33					23.4	24.9		1.58	16.7	23	19.3	16.6		0.5	4.4		
			Spruce	195					21.4	22.5		7.75	84.4	203	17.1	14.8		0.5	4.2		
			Spruce	665					15.9	12.4		8.1	72.9	258	9.1	7.6		1.2	7.1		
			Birch	3					20.6	18.6		0.1	0.6	10	13.4	10.4		0.1	0.5		

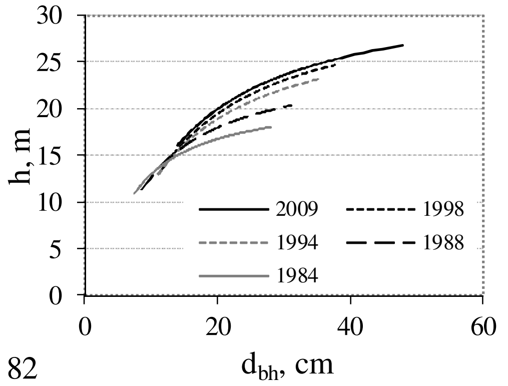
*Green color indicates regeneration.

Appendix 3: The dynamics of modelled height curves in analysed permanent experimental plots and all inventories.

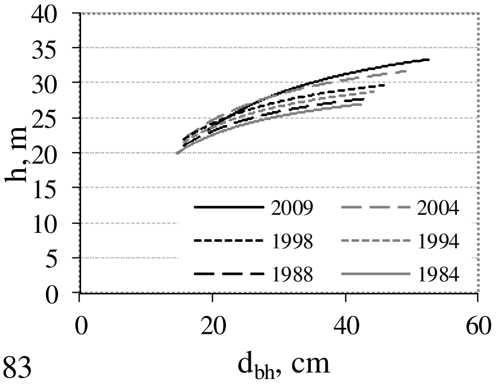
(a) The dynamics of modelled height curves.



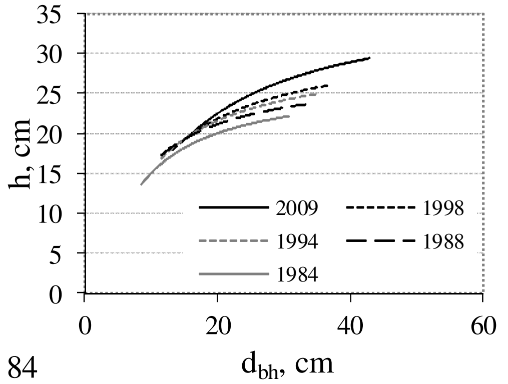
81



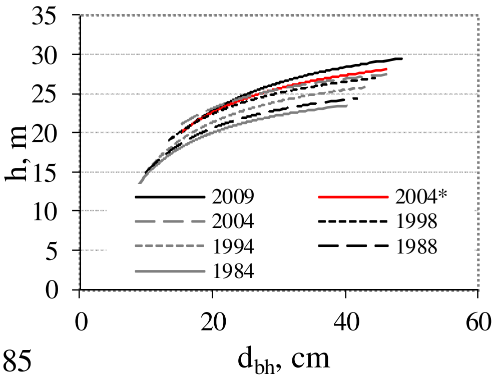
82



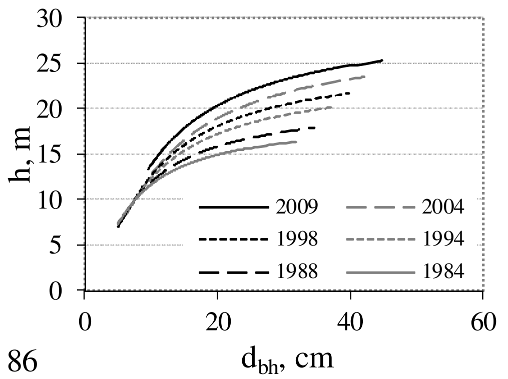
83



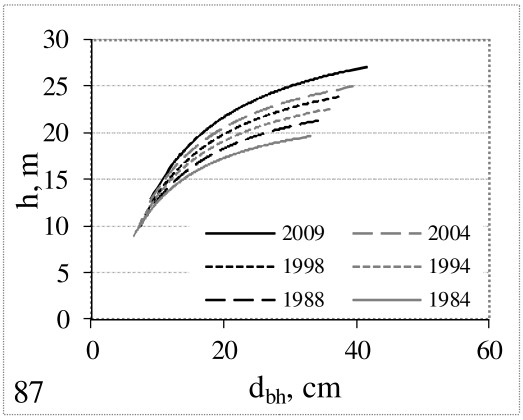
84

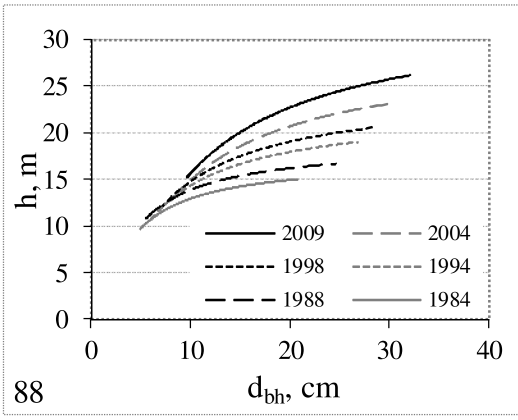


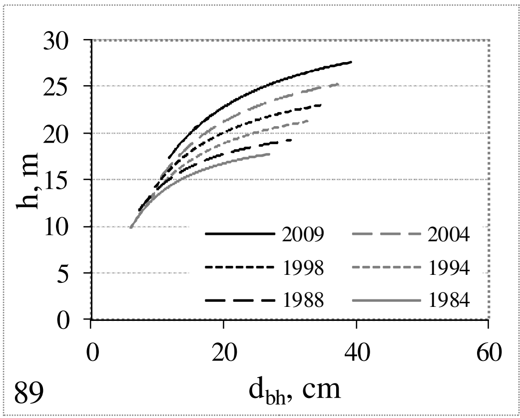
85

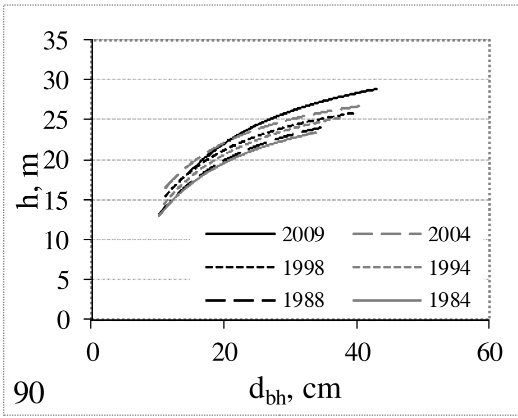


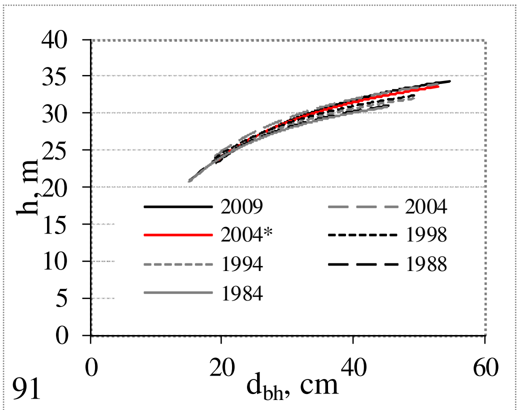
86

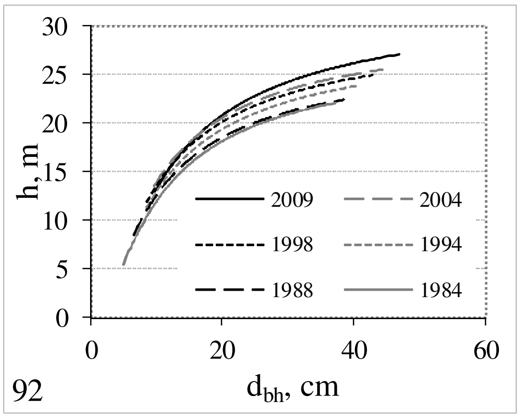

h, m
d_{bh}, cm
2009
2004
1998
1994
1988
1984
87

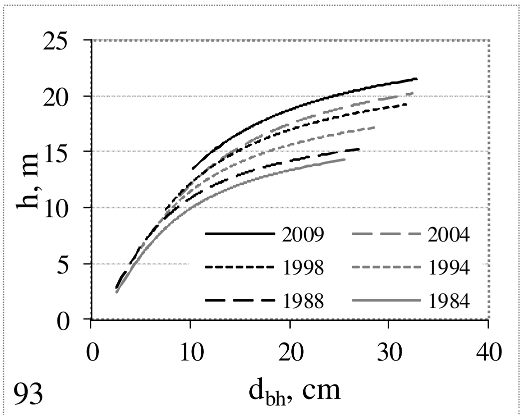

h, m
d_{bh}, cm
2009
2004
1998
1994
1988
1984
88


h, m
d_{bh}, cm
2009
2004
1998
1994
1988
1984
89


h, m
d_{bh}, cm
2009
2004
1998
1994
1988
1984
90


h, m
d_{bh}, cm
2009
2004
2004*
1998
1994
1988
1984
91


h, m
d_{bh}, cm
2009
2004
1998
1994
1988
1984
92


h, m
d_{bh}, cm
2009
2004
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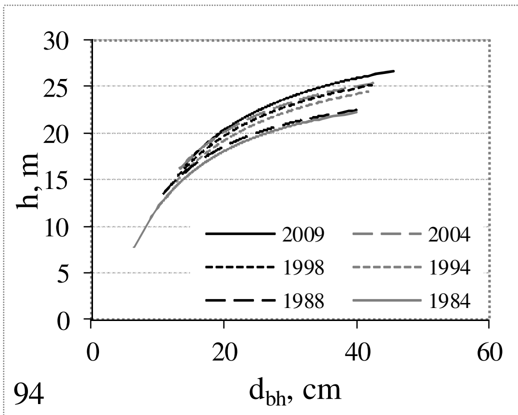
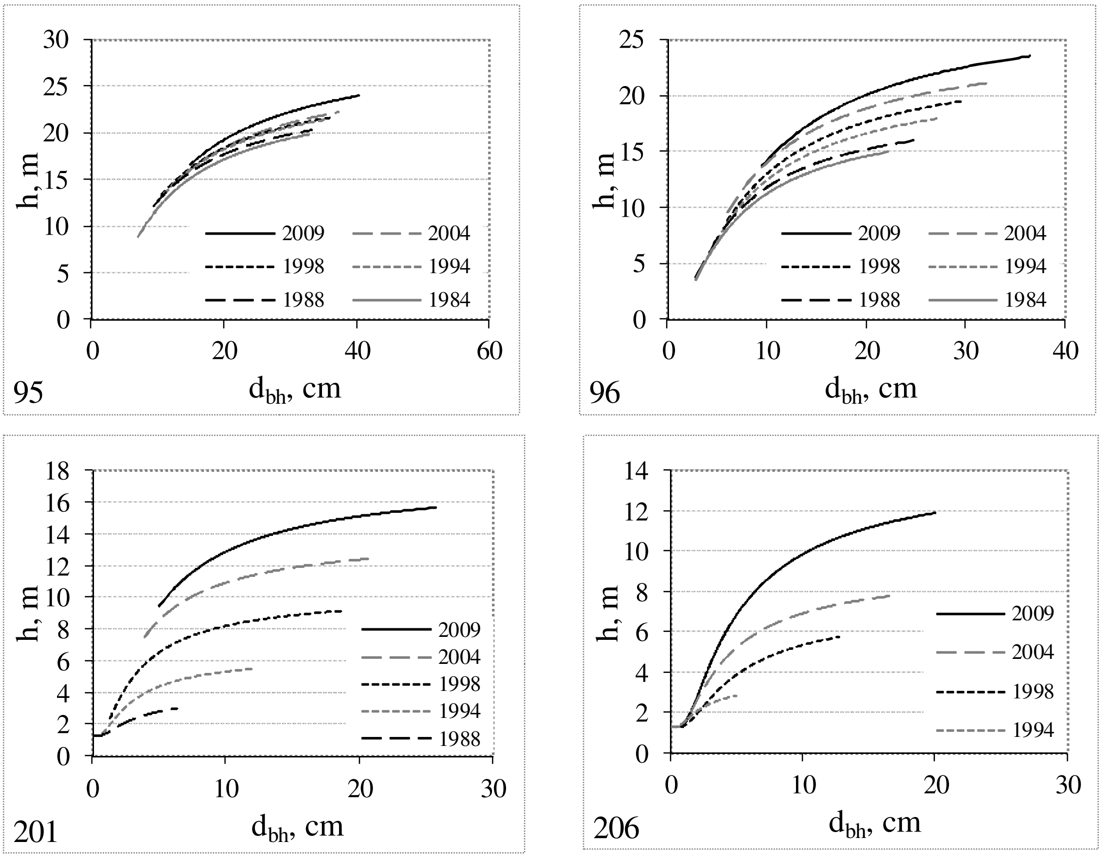
1984
93


h, m
d_{bh}, cm
2009
2004
1998
1994
1988
1984
94



* Red colour indicates smoothed height curves.

(b) The statistical parameters of height models for each permanent experimental plot and inventory.

PEPs	inv	R^2	Coeff values		Std Error of coeff	
			a_0	a_1	a_0	a_1
81	1984	0.75	-11.8938	3.5446	0.96	0.04
	1988	0.83	-12.0773	3.5533	0.78	0.03
	1994	0.79	-11.7798	3.5548	0.90	0.03
	1998	0.70	-12.0472	3.5778	1.19	0.04
	2004	0.71	-11.4738	3.5742	1.18	0.04
	2009					
82	1984	0.68	-5.5299	3.0178	0.42	0.03
	1988	0.70	-7.4503	3.1894	0.55	0.03
	1994	0.78	-10.0382	3.3729	0.66	0.03
	1998	0.75	-10.7426	3.4396	0.90	0.04
	2004					
	2009	0.75	-10.6471	3.4618	0.83	0.03
83	1984	0.56	-7.0242	3.4134	0.79	0.03
	1988	0.59	-7.1284	3.4441	0.71	0.03
	1994	0.63	-7.3527	3.4809	0.68	0.02
	1998	0.70	-7.5245	3.5133	0.62	0.02
	2004	0.69	-8.7374	3.5934	0.74	0.02
	2009	0.55	-11.4212	3.6884	0.78	0.02
84	1984	0.63	-6.1334	3.2400	0.49	0.03
	1988	0.58	-5.8863	3.2862	0.52	0.02
	1994	0.67	-7.0798	3.3677	0.54	0.02
	1998	0.71	-8.0800	3.4297	0.59	0.02
	2004					

PEPs	Inv	R^2	Coeff values		Std Error of coeff	
			a_0	a_1	a_0	a_1
90	1984	0.80	-9.1803	3.3693	0.59	0.03
	1988	0.81	-9.3960	3.3974	0.59	0.03
	1994	0.74	-9.1464	3.4224	0.74	0.03
	1998	0.72	-8.4673	3.4171	0.74	0.03
	2004	0.75	-7.8602	3.4317	0.65	0.03
	2009	0.69	-10.5540	3.5633	0.80	0.03
91	1984	0.54	-9.2802	3.5945	1.32	0.05
	1988	0.47	-9.3378	3.6022	1.53	0.05
	1994	0.47	-9.7438	3.6250	1.67	0.05
	1998	0.57	-9.7520	3.6377	1.38	0.04
	2004	0.56	-10.358	3.683	1.49	0.04
	2004*	0.52	-11.0792	3.6872	1.59	0.05
	2009	0.46	-11.9643	3.7203	1.84	0.05
92	1984	0.80	-9.0679	3.2793	0.55	0.03
	1988	0.79	-8.4142	3.2694	0.52	0.03
	1994	0.80	-8.6760	3.3300	0.58	0.03
	1998	0.81	-8.4990	3.3617	0.58	0.03
	2004	0.76	-8.3339	3.3754	0.65	0.03
	2009	0.70	-9.6471	3.4552	0.53	0.02
93	1984	0.84	-6.6306	2.8253	0.44	0.04
	1988	0.83	-5.9088	2.8554	0.42	0.03
	1994	0.75	-6.7966	3.0047	0.55	0.04
	1998	0.78	-7.2330	3.1164	0.58	0.03

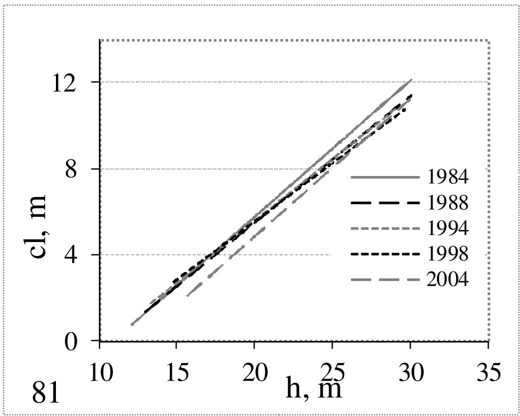
PEPs	inv	R^2	Coeff values		Std Error of coeff	
			a_0	a_1	a_0	a_1
	2009	0.71	-10.5214	3.5837	0.54	0.02
85	1984	0.55	-6.7138	3.2689	0.64	0.04
	1988	0.59	-6.8563	3.3074	0.63	0.03
	1994	0.66	-7.4639	3.3757	0.59	0.03
	1998	0.57	-7.0537	3.4068	0.79	0.03
	2004	0.54	-6.2972	3.4021	0.78	0.03
	2004*	0.55	-8.0004	3.4629	0.84	0.04
	2009	0.58	-9.1359	3.5299	0.62	0.02
86	1984	0.67	-5.4032	2.8867	0.41	0.04
	1988	0.76	-6.1971	2.9918	0.38	0.03
	1994	0.72	-7.2769	3.1351	0.52	0.04
	1998	0.77	-7.7905	3.2137	0.53	0.03
	2004	0.82	-8.4588	3.3001	0.51	0.03
	2009	0.70	-8.2634	3.3635	0.43	0.02
87	1984	0.77	-6.8876	3.1206	0.42	0.03
	1988	0.80	-7.7453	3.2253	0.44	0.03
	1994	0.78	-7.9016	3.2786	0.50	0.03
	1998	0.81	-8.4125	3.3444	0.51	0.03
	2004	0.78	-8.3095	3.3758	0.57	0.03
	2009	0.74	-8.9473	3.4655	0.43	0.02
88	1984	0.51	-3.1499	2.7747	0.32	0.03
	1988	0.65	-3.3672	2.8735	0.26	0.02
	1994	0.73	-4.8373	3.0577	0.32	0.03
	1998	0.70	-5.4571	3.1524	0.48	0.03
	2004	0.74	-7.0134	3.3197	0.53	0.03
	2009	0.71	-7.8902	3.4620	0.55	0.03
89	1984	0.63	-4.9443	2.9887	0.42	0.03
	1988	0.65	-5.1247	3.0600	0.42	0.03
	1994	0.69	-6.4909	3.1952	0.49	0.03
	1998	0.72	-6.8518	3.2775	0.53	0.03
	2004	0.67	-7.8859	3.3892	0.71	0.04
	2009	0.67	-8.2234	3.4818	0.45	0.02

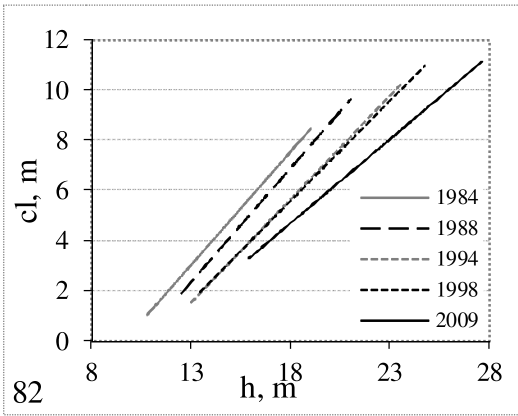
PEPs	Inv	R^2	Coeff values		Std Error of coeff	
			a_0	a_1	a_0	a_1
	2004	0.71	-8.0792	3.1916	0.78	0.04
	2009	0.60	-7.4519	3.2355	0.52	0.03
94	1984	0.65	-8.9029	3.2684	0.80	0.04
	1988	0.68	-8.1293	3.2591	0.68	0.03
	1994	0.72	-9.8216	3.3797	0.76	0.03
	1998	0.73	-9.8178	3.4068	0.77	0.03
	2004	0.69	-9.2886	3.4021	0.87	0.03
	2009	0.72	-10.2268	3.4606	0.51	0.02
95	1984	0.66	-7.9570	3.1648	0.71	0.04
	1988	0.67	-7.2936	3.1657	0.65	0.03
	1994	0.72	-8.1077	3.2415	0.66	0.03
	1998	0.61	-7.8321	3.2327	0.85	0.04
	2004	0.51	-8.6044	3.2739	1.27	0.05
	2009	0.57	-9.2471	3.3531	0.68	0.03
96	1984	0.78	-5.7749	2.8794	0.41	0.04
	1988	0.74	-5.5806	2.9146	0.43	0.04
	1994	0.66	-6.2963	3.0465	0.63	0.05
	1998	0.68	-6.6242	3.1280	0.71	0.05
	2004	0.68	-6.4007	3.1878	0.81	0.05
	2009	0.64	-7.4608	3.3076	0.62	0.03
201	1984					
	1988	0.83	-2.9109	1.0073	0.20	0.07
	1994	0.88	-2.6369	1.6639	0.14	0.03
	1998	0.71	-2.7516	2.2120	0.17	0.02
	2004	0.62	-2.7925	2.5478	0.21	0.02
	2009	0.63	-3.5120	2.8042	0.25	0.02
206	1984					
	1988					
	1994	0.68	-2.1955	0.8893	0.24	0.10
	1998	0.86	-4.4324	1.8478	0.32	0.06
	2004	0.63	-3.5431	2.0850	0.38	0.05
	2009	0.83	-4.2528	2.5745	0.24	0.03

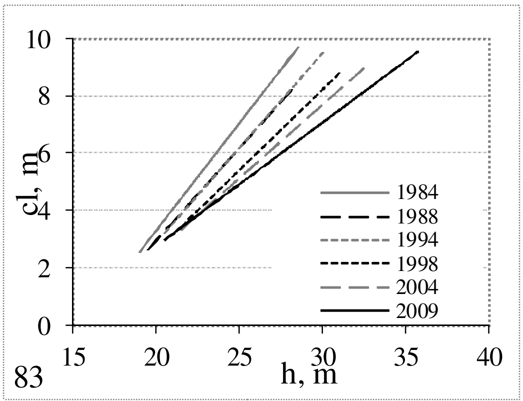
*Statistical parameters of smoothed height curves.

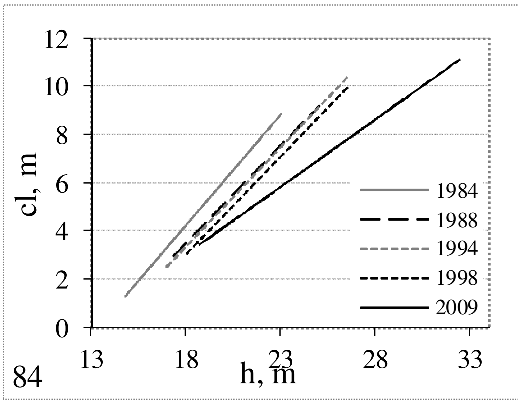
Appendix 4: The dynamics of modelled tree crown length curves in analysed permanent experimental plots and all inventories.

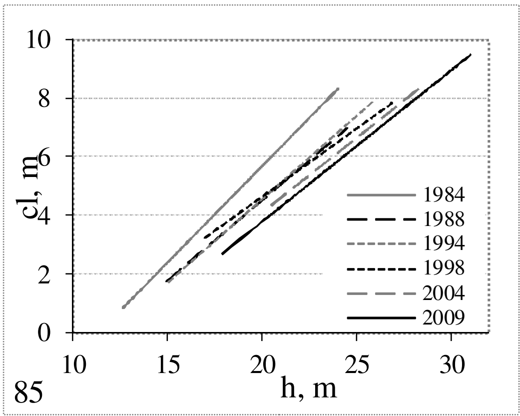
(a). The dynamics of crown length curves in permanent experimental plots during all inventories.

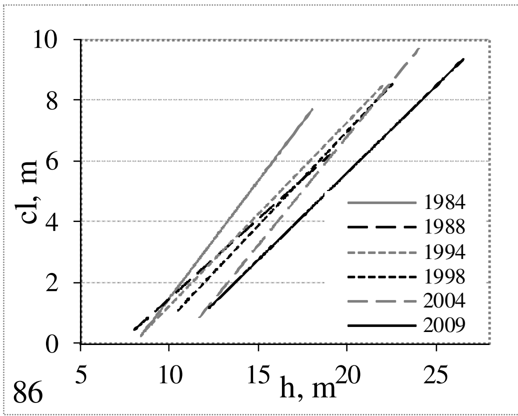


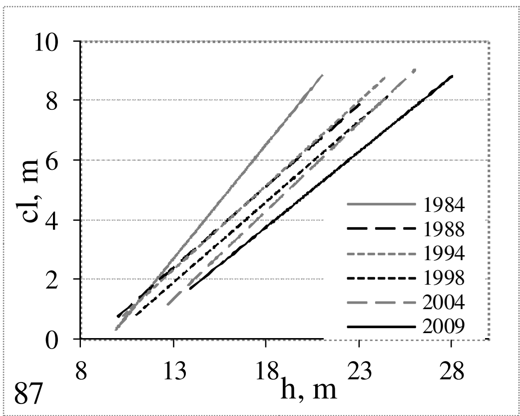


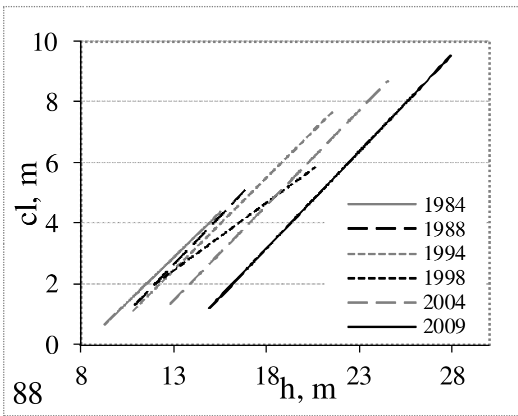


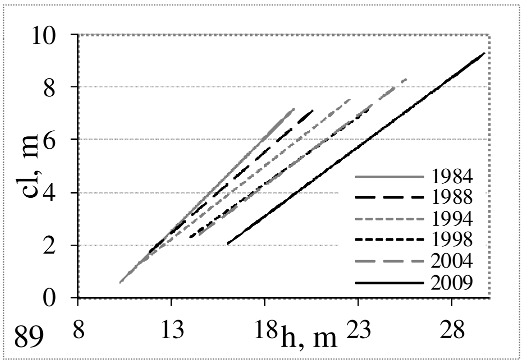












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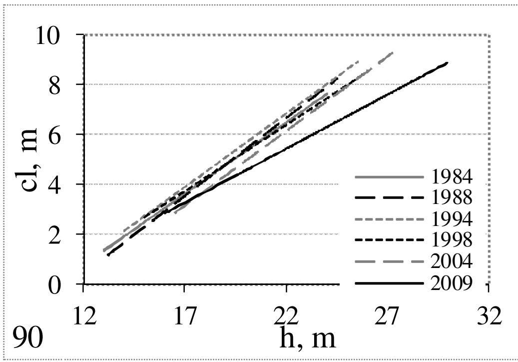

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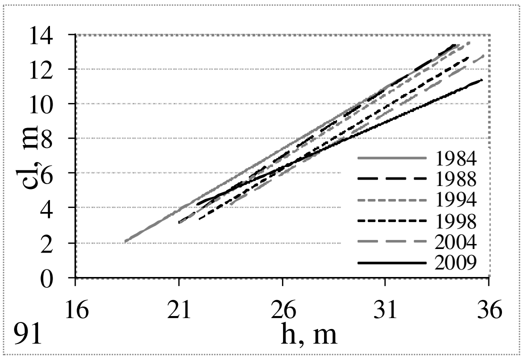

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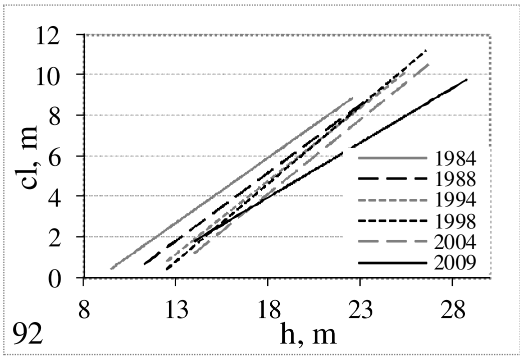

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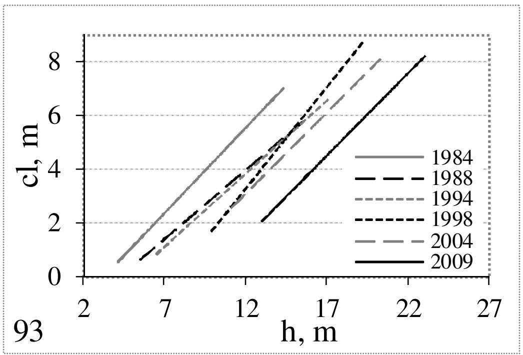

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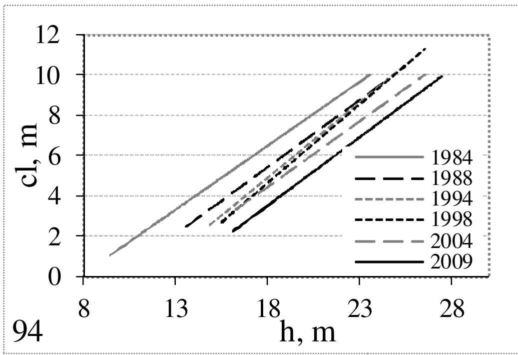

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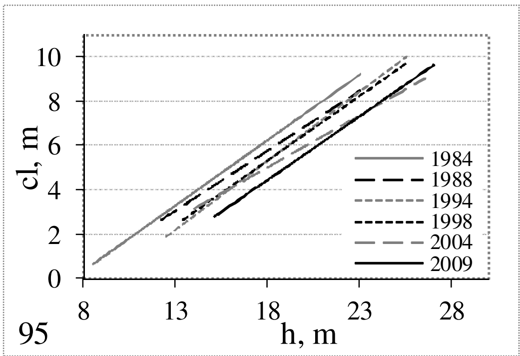

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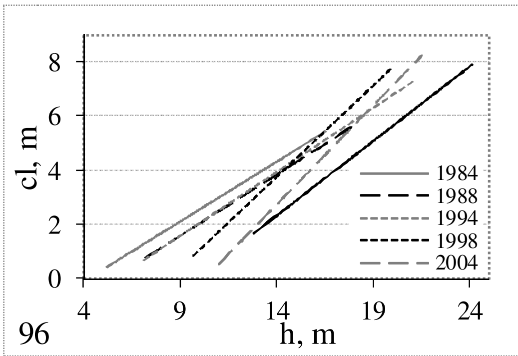

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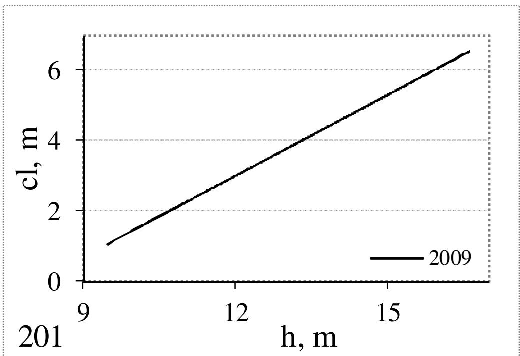
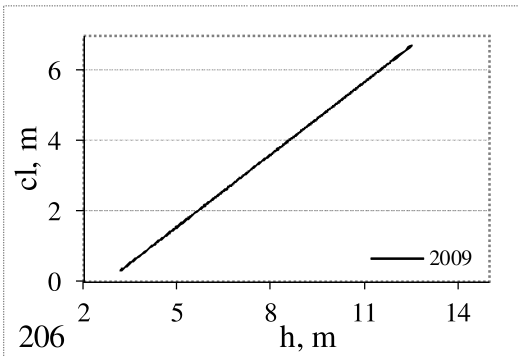


201



206

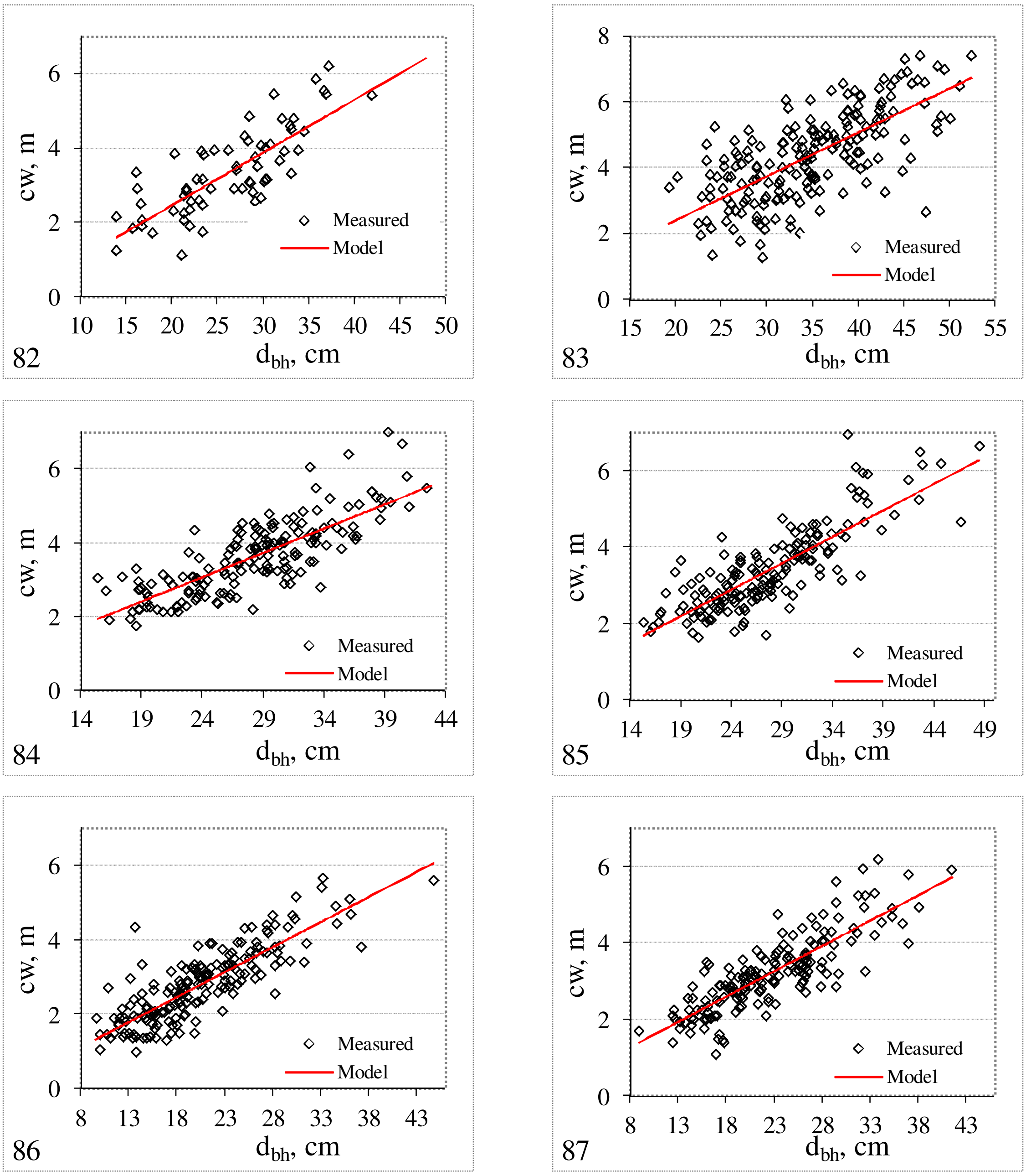
(b). The statistical parameters of tree crown length models for each permanent experimental plot and inventory.

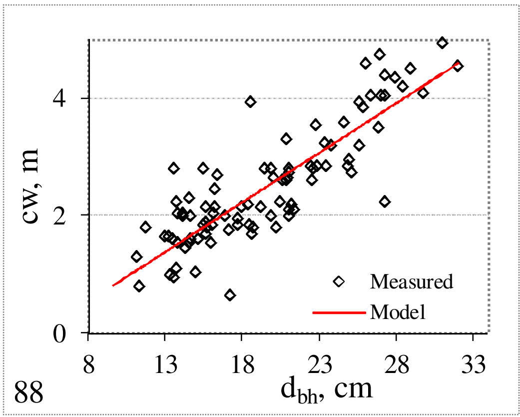
inv	PEPs	R^2	Sign	Coeff values		Std Error of coeff		Sign of coeff		PEPs	R^2	Sign	Coeff values		Std Error of coeff		Sign of coeff	
				a_0	a_1	a_0	a_1	a_0	a_1				a_0	a_1	a_0	a_1	a_0	a_1
1984	81	0.54	5.90E-11	-6.89	0.64	1.8	0.1	3.50E-04	5.90E-11	90	0.74	8.50E-21	-6.07	0.57	0.8	0	2.50E-10	8.50E-21
1988		0.63	2.50E-13	-6.27	0.59	1.5	0.1	6.90E-05	2.50E-13		0.74	1.40E-20	-7.05	0.62	0.9	0	1.70E-10	1.40E-20
1994		0.57	1.70E-11	-5.87	0.57	1.6	0.1	7.70E-04	1.70E-11		0.69	6.50E-17	-6.1	0.59	1.1	0.1	7.40E-07	6.50E-17
1998		0.48	1.10E-08	-5.23	0.54	2	0.1	1.10E-02	1.10E-08		0.55	2.00E-11	-5.26	0.53	1.4	0.1	5.20E-04	2.00E-11
2004		0.57	7.00E-10	-7.88	0.64	2.1	0.1	5.50E-04	7.00E-10		0.5	1.10E-09	-6.97	0.6	1.9	0.1	6.40E-04	1.10E-09
2009											0.39	8.40E-11	-4.08	0.43	1.5	0.1	6.90E-03	8.40E-11
1984	82	0.66	1.90E-23	-8.69	0.9	1.1	0.1	2.30E-12	1.90E-23	91	0.57	4.50E-10	-10.84	0.7	2.5	0.1	6.20E-05	4.50E-10
1988		0.66	4.40E-22	-9.44	0.91	1.2	0.1	2.20E-11	4.40E-22		0.71	1.20E-13	-12.97	0.77	2.1	0.1	1.40E-07	1.20E-13
1994		0.82	3.40E-29	-9.19	0.83	0.9	0	2.00E-16	3.40E-29		0.69	3.10E-12	-12.4	0.74	2.2	0.1	1.60E-06	3.10E-12
1998		0.81	3.00E-21	-8.78	0.8	1.1	0.1	7.70E-11	3.00E-21		0.57	5.50E-09	-12.39	0.72	2.9	0.1	1.00E-04	5.50E-09
2004		0.81	3.00E-21	-8.78	0.8	1.1	0.1	7.70E-11	3.00E-21		0.53	2.70E-08	-12.11	0.7	3.1	0.1	3.60E-04	2.70E-08
2009		0.58	1.50E-13	-7.34	0.67	1.6	0.1	2.20E-05	1.50E-13		0.37	7.00E-07	-7.21	0.52	2.9	0.1	1.60E-02	7.00E-07
1984	83	0.66	1.10E-16	-1.84	0.44	0.5	0	1.50E-04	1.10E-16	92	0.64	3.30E-19	-5.66	0.65	0.9	0.1	3.50E-08	3.30E-19
1988		0.62	5.50E-15	-2.46	0.45	0.6	0	5.60E-05	5.50E-15		0.77	1.30E-26	-6.9	0.67	0.8	0	5.60E-14	1.30E-26
1994		0.66	1.20E-14	-2.66	0.47	0.7	0	1.80E-04	1.20E-14		0.79	4.40E-24	-8.19	0.72	0.9	0	3.80E-13	4.40E-24
1998		0.73	1.00E-13	-5.65	0.67	1	0.1	1.20E-06	1.00E-13		0.8	5.10E-24	-9.15	0.77	1	0	3.70E-13	5.10E-24
2004		0.64	5.60E-09	-7.48	0.73	1.7	0.1	1.10E-04	5.60E-09		0.68	2.40E-16	-9.05	0.73	1.4	0.1	3.10E-08	2.40E-16
2009		0.76	2.00E-34	-1.86	0.69	0.4	0	6.70E-07	2.00E-34		0.54	6.50E-30	-5.75	0.54	0.9	0	8.60E-10	6.50E-30
1984	84	0.62	1.20E-15	-11.68	0.75	1.8	0.1	6.20E-09	1.20E-15	93	0.68	1.20E-16	-2.05	0.63	0.6	0.1	1.50E-03	1.20E-16
1988		0.56	5.30E-19	-11.02	0.81	1.6	0.1	3.20E-10	5.30E-19		0.82	8.60E-25	-2.17	0.51	0.4	0	3.20E-07	8.60E-25
1994		0.64	5.80E-22	-11.47	0.83	1.5	0.1	7.20E-12	5.80E-22		0.59	1.70E-12	-2.67	0.54	0.9	0.1	3.20E-03	1.70E-12
1998		0.52	3.00E-12	-8.65	0.56	1.8	0.1	1.00E-05	3.00E-12		0.8	8.50E-20	-5.77	0.76	0.8	0.1	6.90E-09	8.50E-20
2004		0.61	2.70E-18	-11.58	0.81	1.7	0.1	1.30E-09	2.70E-18		0.52	1.60E-09	-4.13	0.6	1.4	0.1	5.10E-03	1.60E-09
2009		0.59	1.80E-33	-6.99	0.56	0.9	0	5.70E-12	1.80E-33		0.59	7.70E-31	-5.89	0.61	0.8	0	4.10E-12	7.70E-31
1984	85	0.44	1.30E-13	-7.47	0.66	1.5	0.1	2.30E-06	1.30E-13	94	0.53	1.50E-13	-4.92	0.64	1.3	0.1	2.80E-04	1.50E-13
1988		0.5	6.80E-15	-6.41	0.55	1.2	0.1	7.70E-07	6.80E-15		0.71	4.60E-20	-6.53	0.67	1	0.1	7.60E-09	4.60E-20
1994		0.63	2.50E-20	-6.84	0.57	1	0	2.20E-09	2.50E-20		0.81	6.50E-26	-8.53	0.75	0.9	0	8.00E-14	6.50E-26
1998		0.36	8.30E-08	-4.65	0.47	1.8	0.1	1.20E-02	8.30E-08		0.79	1.80E-24	-9.32	0.78	1	0	4.30E-13	1.80E-24
2004		0.26	3.90E-05	-6.06	0.51	2.8	0.1	3.40E-02	3.90E-05		0.58	3.00E-12	-7.27	0.65	1.6	0.1	4.00E-05	3.00E-12
2009		0.47	9.00E-25	-6.55	0.52	1.1	0	1.10E-08	9.00E-25		0.6	1.90E-36	-8.65	0.68	1	0	8.20E-16	1.90E-36

inv	PEPs	R^2	Sign	Coeff values		Std Error of coeff		Sign of coeff		PEPs	R^2	Sign	Coeff values		Std Error of coeff		Sign of coeff	
				a_0	a_1	a_0	a_1	a_0	a_1				a_0	a_1	a_0	a_1	a_0	a_1
1984	86	0.71	1.20E-26	-6.22	0.77	0.6	0.1	6.90E-16	1.20E-26	95	0.55	3.30E-14	-4.35	0.59	1	0.1	8.50E-05	3.30E-14
1988		0.74	6.40E-30	-3.73	0.52	0.4	0	5.40E-14	6.40E-30		0.55	7.30E-14	-3.94	0.54	1	0.1	2.60E-04	7.30E-14
1994		0.8	1.40E-31	-4.77	0.6	0.5	0	1.60E-15	1.40E-31		0.71	9.90E-20	-5.87	0.62	0.9	0	9.20E-09	9.90E-20
1998		0.73	3.10E-22	-5.36	0.62	0.7	0	2.40E-10	3.10E-22		0.63	1.30E-14	-5.14	0.58	1.1	0.1	1.50E-05	1.30E-14
2004		0.71	5.30E-19	-7.48	0.72	1	0.1	6.90E-10	5.30E-19		0.49	1.40E-08	-3.39	0.47	1.4	0.1	1.60E-02	1.40E-08
2009		0.66	1.10E-42	-5.8	0.57	0.6	0	8.90E-17	1.10E-42		0.49	2.20E-23	-5.85	0.57	1	0	6.50E-08	2.20E-23
1984	87	0.77	1.20E-29	-7.25	0.77	0.7	0	7.20E-18	1.20E-29	96	0.66	1.10E-16	-1.84	0.44	0.5	0	1.50E-04	1.10E-16
1988		0.81	5.00E-31	-4.69	0.55	0.5	0	3.30E-15	5.00E-31		0.62	5.50E-15	-2.46	0.45	0.6	0	5.60E-05	5.50E-15
1994		0.82	5.00E-32	-5	0.57	0.5	0	2.90E-15	5.00E-32		0.66	1.20E-14	-2.66	0.47	0.7	0	1.80E-04	1.20E-14
1998		0.75	1.40E-22	-5.12	0.54	0.7	0	4.30E-10	1.40E-22		0.73	1.00E-13	-5.65	0.67	1	0.1	1.20E-06	1.00E-13
2004		0.71	8.00E-19	-6.3	0.59	0.9	0	7.00E-09	8.00E-19		0.64	5.60E-09	-7.48	0.73	1.7	0.1	1.10E-04	5.60E-09
2009		0.67	3.50E-42	-5.31	0.51	0.6	0	4.80E-15	3.50E-42		0.59	1.40E-19	-5.36	0.55	1	0	2.10E-07	1.40E-19
1984	88	0.52	1.90E-16	-4.83	0.59	0.8	0.1	6.50E-09	1.90E-16	201								
1988		0.62	6.50E-22	-5.62	0.64	0.7	0.1	9.20E-12	6.50E-22									
1994		0.78	9.90E-32	-5.46	0.61	0.5	0	3.30E-17	9.90E-32									
1998		0.6	1.20E-13	-3.32	0.45	0.8	0	1.20E-04	1.20E-13									
2004		0.75	1.60E-21	-6.69	0.63	0.9	0	7.10E-11	1.60E-21									
2009		0.73	2.90E-27	-8.31	0.64	0.9	0	2.80E-14	2.90E-27		0.69		-6.21	0.77	0.6	0	4.90E-17	5.10E-33
1984	89	0.6	1.50E-19	-6.69	0.71	0.9	0.1	1.50E-10	1.50E-19	206								
1988		0.62	2.20E-19	-5.54	0.62	0.9	0.1	1.10E-08	2.20E-19									
1994		0.64	9.30E-20	-4.99	0.56	0.8	0	4.70E-08	9.30E-20									
1998		0.55	1.00E-13	-4.83	0.51	1.1	0.1	2.70E-05	1.00E-13									
2004		0.62	4.80E-15	-5.33	0.54	1.1	0.1	9.90E-06	4.80E-15									
2009		0.54	7.10E-32	-6.36	0.53	0.9	0	6.20E-12	7.10E-32		0.76		-1.86	0.69	0.4	0	6.70E-07	2.00E-34

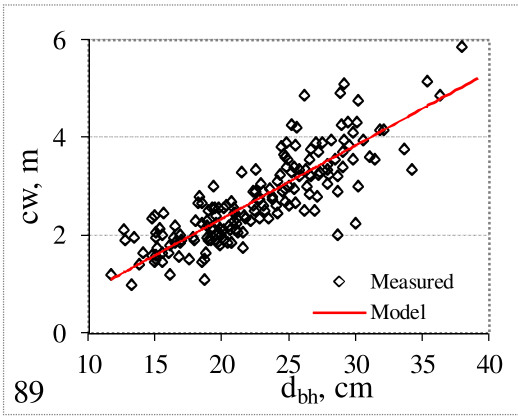
Appendix 5: The modelled crown width curves for each permanent experimental plot and last inventory.

(a). The modelled crown width curves for all permanent experimental plots and for the last (2009) inventory.

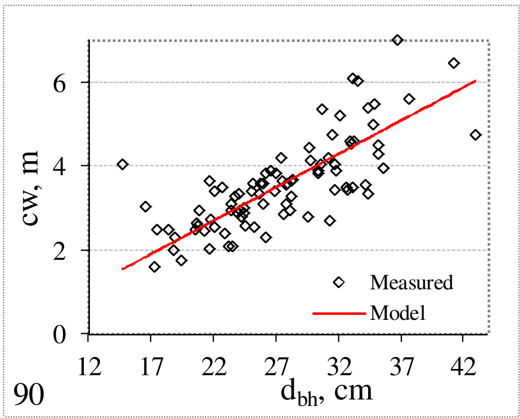




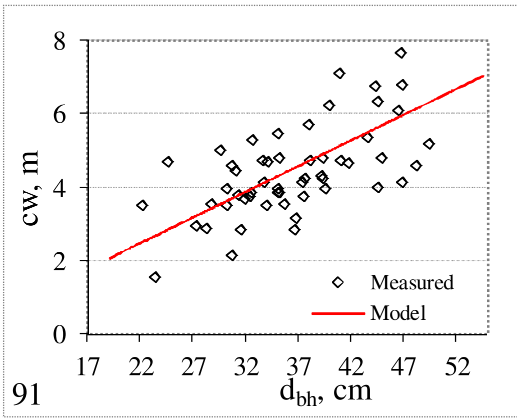
88



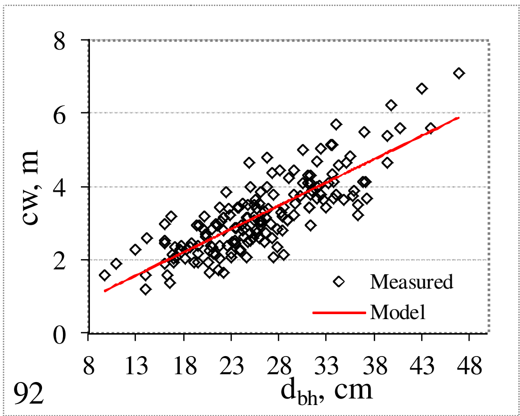
89



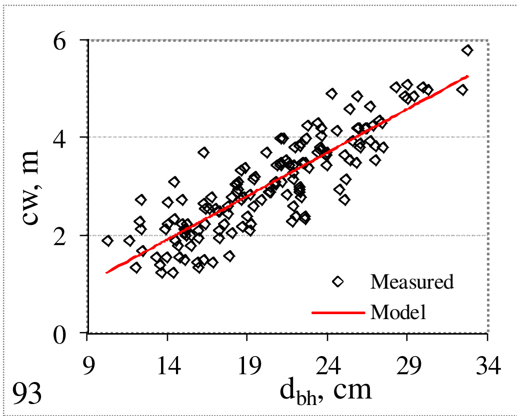
90



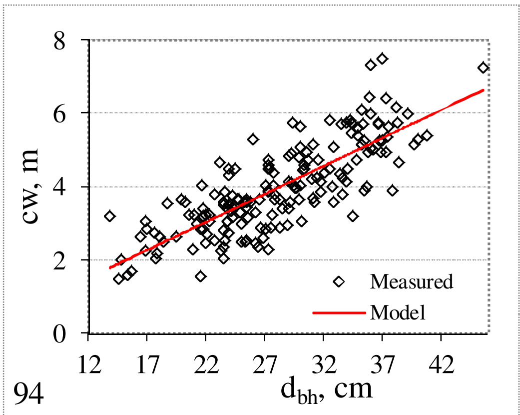
91



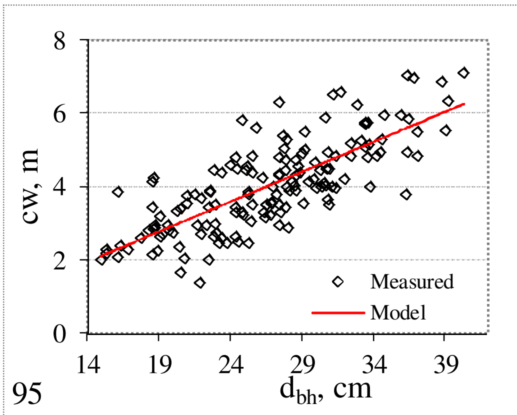
92



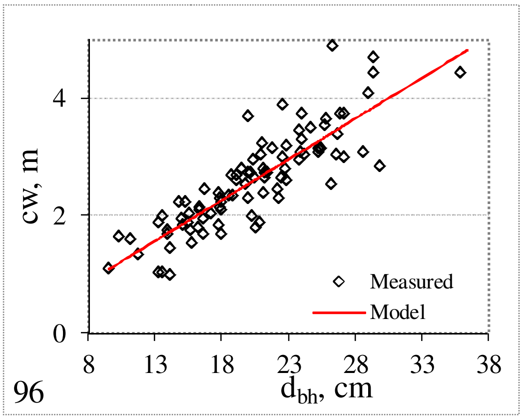
93

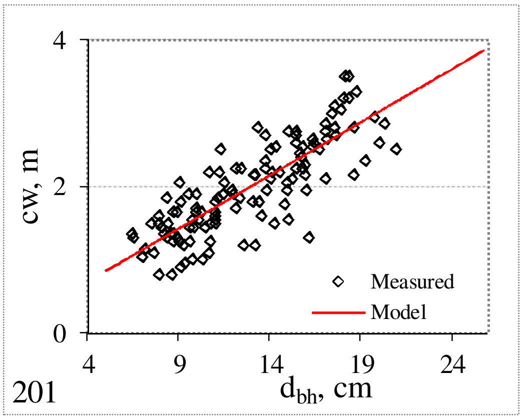


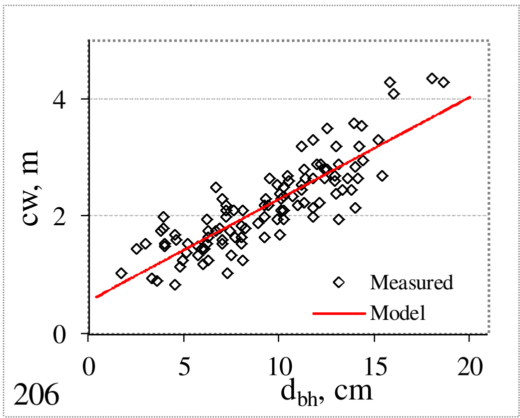
94



95







(b) The statistical parameters of tree crown widths models for each permanent experimental plot and last inventory.

PEPs	**inv**	**R^2**	**Sign**	**Coeff values**		**Std Error of coeff**		**Sign of coeff**	
				a_0	**a_1**	**a_0**	**a_1**	**a_0**	**a_1**
81	2009								
82	2009	0.62	7.5E-15	-0.36111	0.14173	0.38	0.014	3.4E-01	7.5E-15
83	2009	0.50	2.6E-30	-0.24692	0.133472	0.34	0.010	4.7E-01	2.6E-30
84	2009	0.64	2.2E-38	-0.08756	0.131835	0.22	0.008	6.9E-01	2.2E-38
85	2009	0.70	4.1E-45	-0.42275	0.138324	0.20	0.007	3.6E-02	4.1E-45
86	2009	0.73	8.0E-51	0.041609	0.134625	0.13	0.006	7.6E-01	8.0E-51
87	2009	0.69	3.5E-45	0.21736	0.132511	0.16	0.007	1.7E-01	3.5E-45
88	2009	0.76	2.7E-29	-0.79935	0.168773	0.21	0.010	2.0E-04	2.7E-29
89	2009	0.76	5.5E-56	-0.63641	0.149477	0.15	0.006	2.8E-05	5.5E-56
90	2009	0.64	1.4E-20	-0.78566	0.159047	0.37	0.013	3.5E-02	1.4E-20
91	2009	0.49	1.8E-09	-0.59275	0.139887	0.73	0.019	4.2E-01	1.8E-09
92	2009	0.67	2.1E-42	-0.06585	0.127201	0.18	0.007	7.2E-01	2.1E-42
93	2009	0.75	1.2E-46	-0.56927	0.178342	0.18	0.008	1.6E-03	1.2E-46
94	2009	0.64	8.0E-41	-0.31303	0.152813	0.25	0.009	2.1E-01	8.0E-41
95	2009	0.59	5.3E-31	-0.31605	0.163121	0.30	0.011	3.0E-01	5.3E-31
96	2009	0.77	7.3E-31	-0.22193	0.138727	0.17	0.008	1.9E-01	7.3E-31
201	2009	0.70	1.4E-33	0.128298	0.144857	0.11	0.009	2.7E-01	1.4E-33
206	2009	0.73	1.9E-31	0.570574	0.173283	0.10	0.010	2.8E-07	1.9E-31

Appendix 6: The results of partial correlation analysis in all permanent experimental plots and all inventories.

(a). The influence of distance independent competition indices on periodic mean annual tree basal area increment.

		i_{ba}	ln(1+CI$_1$)			ln(1+CI$_2$)					i_{ba}	ln(1+CI$_1$)			ln(1+CI$_2$)		
PEPs	**inv**	**ba**	**ba**	**Partial corr**		**ba**	**Partial corr**		**PEPs**	**inv**	**ba**	**ba**	**Partial corr**		**ba**	**Partial corr**	
		R^2	**R^2**	**r**	**Sign**	**R^2**	**r**	**Sign**			**R^2**	**R^2**	**r**	**Sign**	**R^2**	**r**	**Sign**
81	2009								90	2009		0.59			0.93		
81	2004		0.92			0.93			90	2004	0.307	0.58	0.161	0.12	0.93	-0.107	0.31
81	1998	0.17	0.93	0.071	0.54	0.96	-0.09	0.43	90	1998	0.589	0.57	0.158	0.13	0.94	-0.127	0.23
81	1994	0.254	0.92	0.238	0.01	0.93	-0.122	0.22	90	1994	0.28	0.91	0	1	0.92	-0.028	0.79
81	1988	0.331	0.92	0.101	0.34	0.92	-0.078	0.46	90	1988	0.421	0.6	0.057	0.55	0.92	-0.12	0.21
81	1984	0.466	0.93	0.343	0	0.91	-0.325	0	90	1984	0.475	0.9	-0.229	0.01	0.93	0.063	0.46
82	2009		0.92			0.91			91	2009		0.57			0.92		
82	2004								91	2004	0.36	0.57	0.117	0.28	0.93	-0.119	0.28
82	1998	0.518	0.93	0.187	0.38	0.92	-0.206	0.33	91	1998	0.407	0.57	-0.301	0	0.93	0.146	0.17
82	1994	0.211	0.59	-0.101	0.59	0.93	-0.194	0.3	91	1994	0.222	0.54	0.292	0.01	0.94	-0.173	0.14
82	1988	0.756	0.91	-0.03	0.84	0.94	0.109	0.46	91	1988	0.455	0.56	-0.255	0.01	0.93	0.082	0.43
82	1984	0.596	0.65	0.267	0.03	0.94	-0.155	0.22	91	1984	0.235	0.55	0.062	0.55	0.93	-0.028	0.79
83	2009		0.92			0.95			92	2009		0.93			0.91		
83	2004	0.466	0.92	0.027	0.74	0.95	-0.046	0.58	92	2004	0.447	0.96	0.193	0.05	0.93	-0.13	0.18
83	1998	0.439	0.93	0.084	0.31	0.96	-0.027	0.75	92	1998	0.502	0.95	0.066	0.52	0.91	-0.053	0.6
83	1994	0.403	0.92	0.156	0.05	0.95	-0.141	0.07	92	1994	0.461	0.94	0.009	0.92	0.89	-0.066	0.46
83	1988	0.265	0.93	0.155	0.06	0.95	-0.126	0.12	92	1988	0.333	0.66	0.048	0.59	0.89	-0.248	0.01
83	1984	0.381	0.94	0.153	0.04	0.95	-0.133	0.07	92	1984	0.5	0.69	0.196	0.01	0.87	-0.246	0
84	2009		0.54			0.93			93	2009		0.89			0.94		
84	2004								93	2004	0.688	0.91	0	1	0.94	-0.002	0.99
84	1998	0.737	0.86	-0.141	0.16	0.95	0.006	0.95	93	1998	0.622	0.91	-0.286	0.07	0.95	0.254	0.11
84	1994	0.312	0.85	0.214	0.04	0.93	-0.106	0.32	93	1994	0.406	0.94	-0.092	0.52	0.95	0.043	0.77
84	1988	0.368	0.9	-0.208	0.04	0.95	0.11	0.29	93	1988	0.653	0.93	-0.231	0.08	0.93	0.115	0.38
84	1984	0.451	0.61	0.072	0.44	0.95	0.059	0.53	93	1984	0.557	0.93	0.068	0.6	0.9	-0.016	0.9
85	2009		0.96			0.93			94	2009		0.82			0.93		
85	2004	0.51	0.96	0.211	0.04	0.94	-0.169	0.1	94	2004	0.399	0.86	0.077	0.41	0.95	-0.045	0.63
85	1998	0.574	0.96	-0.16	0.11	0.94	0.164	0.11	94	1998	0.05	0.85	0.07	0.52	0.95	-0.106	0.32
85	1994	0.364	0.94	-0.181	0.08	0.94	0.213	0.04	94	1994	0.372	0.89	-0.135	0.15	0.95	-0.026	0.78
85	1988	0.647	0.94	-0.136	0.1	0.93	0.114	0.16	94	1988	0.217	0.87	0.311	0	0.94	-0.195	0.03
85	1984	0.479	0.94	-0.049	0.55	0.92	0.015	0.85	94	1984	0.532	0.87	0.14	0.09	0.93	-0.119	0.15

PEPs	inv	i_{ba} ba R^2	ln(1+CI$_1$) ba R^2	ln(1+CI$_1$) Partial corr r	ln(1+CI$_1$) Partial corr Sign	ln(1+CI$_2$) ba R^2	ln(1+CI$_2$) Partial corr r	ln(1+CI$_2$) Partial corr Sign
86	2009		0.79			0.84		
86	2004	0.714	0.83	0.304	0	0.86	-0.415	0
86	1998	0.683	0.87	0.333	0	0.85	-0.294	0
86	1994	0.663	0.86	-0.225	0.03	0.84	0.182	0.08
86	1988	0.659	0.88	0.159	0.06	0.83	-0.257	0
86	1984	0.761	0.9	0.122	0.13	0.82	-0.079	0.33
87	2009		0.69			0.89		
87	2004	0.472	0.69	0.036	0.8	0.91	-0.092	0.52
87	1998	0.448	0.69	-0.025	0.85	0.91	-0.271	0.03
87	1994	0.432	0.68	0.033	0.8	0.85	-0.023	0.85
87	1988	0.536	0.7	0.156	0.15	0.86	-0.285	0.01
87	1984	0.626	0.73	0.235	0.02	0.86	-0.257	0.01
88	2009		0.6			0.92		
88	2004	0.715	0.6	0.274	0.07	0.94	-0.078	0.61
88	1998	0.787	0.62	0.417	0	0.94	0.004	0.98
88	1994	0.53	0.65	0.154	0.28	0.91	-0.213	0.13
88	1988	0.809	0.92	-0.072	0.5	0.89	0.06	0.58
88	1984	0.809	0.68	0.235	0.03	0.89	-0.016	0.88
89	2009		0.63			0.91		
89	2004	0.503	0.66	0.086	0.47	0.92	-0.128	0.28
89	1998	0.704	0.69	0.2	0.08	0.93	-0.02	0.86
89	1994	0.565	0.69	-0.242	0.04	0.92	-0.034	0.77
89	1988	0.748	0.94	0.113	0.25	0.93	-0.08	0.41
89	1984	0.628	0.74	0.072	0.44	0.92	-0.135	0.15

PEPs	inv	i_{ba} ba R^2	ln(1+CI$_1$) ba R^2	ln(1+CI$_1$) Partial corr r	ln(1+CI$_1$) Partial corr Sign	ln(1+CI$_2$) ba R^2	ln(1+CI$_2$) Partial corr r	ln(1+CI$_2$) Partial corr Sign
95	2009		0.86			0.94		
95	2004	0.61	0.89	0.058	0.64	0.94	-0.028	0.82
95	1998	0.399	0.54	0.233	0.07	0.93	-0.023	0.86
95	1994	0.457	0.9	-0.019	0.87	0.92	-0.001	0.99
95	1988	0.342	0.9	0.099	0.35	0.91	-0.106	0.31
95	1984	0.576	0.92	0.118	0.21	0.92	-0.116	0.22
96	2009		0.94			0.9		
96	2004	0.705	0.94	-0.021	0.9	0.92	0.201	0.22
96	1998	0.615	0.95	-0.042	0.79	0.94	0.073	0.64
96	1994	0.29	0.96	0.215	0.15	0.89	-0.224	0.13
96	1988	0.679	0.96	0.016	0.89	0.89	-0.13	0.29
96	1984	0.629	0.96	-0.11	0.35	0.87	0.058	0.62
201_1	2009_1		0.88			0.9		
201_2	2009_2		0.71			0.89		
201_1	2004_1	0.583	0.9	0.077	0.23	0.92	-0.033	0.61
201_2	2004_2	0.638	0.87	-0.167	0.01	0.91	0.087	0.18
201_1	1998_1	0.695	0.9	0.075	0.16	0.89	-0.006	0.91
201_2	1998_2	0.738	0.71	0.049	0.4	0.9	0.034	0.56
201_1	1994_1	0.726	0.8	0.249	0	0.84	-0.113	0.02
201_2	1994_2	0.726	0.78	0.215	0	0.81	-0.152	0
201_1	2009_1		0.58			0.72		
206_2	2009_2		0.6			0.8		
201_1	2004_1	0.727	0.66	0.191	0.01	0.69	-0.068	0.39
206_2	2004_2	0.7	0.84	-0.113	0.17	0.82	0.01	0.9
201_1	1998_1	0.79	0.72	0.183	0.01	0.46	0.007	0.93
206_2	1998_2	0.733	0.7	0.36	0	0.74	-0.147	0.05
Average		0.521	0.8	0.067	0.29	0.9	-0.063	0.4
Share of significant cases					8.00%			14.90%

(b). The influence of distance dependent competition indices combined with selection method HCB 80, on periodic mean annual tree basal area increment.

		i_{ba}	ln(1+CI_3)			ln(1+CI_4)			ln(1+CI_5)			ln(1+CI_6)			ln(1+CI_7)			ln(1+CI_8)		
PEPs	inv	ba	ba	Partial corr		ba	Partial corr		ba	Partial corr		ba	Partial corr		ba	Partial corr		ba	Partial corr	
		R^2	R^2	r	Sign	R^2	r	Sign	R^2	r	Sign	R^2	r	Sign	R^2	R^2	Sign	R^2	r	Sign
81	2009																			
81	2004		0.54			0.63			0.61			0.72			0.62			0.12		
81	1998	0.17	0.42	-0.2	0.08	0.55	-0.238	0.04	0.56	-0.258	0.02	0.68	-0.183	0.11	0.54	-0.196	0.09	0.06	-0.115	0.32
81	1994	0.25	0.49	-0.059	0.55	0.6	-0.076	0.44	0.61	-0.063	0.53	0.72	-0.123	0.21	0.59	-0.086	0.38	0.12	-0.139	0.16
81	1988	0.33	0.52	-0.162	0.12	0.66	-0.108	0.3	0.63	-0.096	0.36	0.76	-0.117	0.26	0.61	-0.139	0.18	0.2	-0.078	0.46
81	1984	0.47	0.58	-0.148	0.1	0.68	-0.289	0	0.63	-0.328	0	0.77	-0.374	0	0.62	-0.262	0	0.23	0.023	0.8
82	2009		0.18			0.41			0.47			0.54			0.36			0		
82	2004																			
82	1998	0.52	0.32	-0.339	0.11	0.36	-0.427	0.04	0.4	-0.456	0.03	0.76	-0.592	0	0.51	-0.466	0.02	0.07	-0.354	0.09
82	1994	0.21	0.28	-0.118	0.53	0.37	-0.266	0.15	0.4	-0.333	0.07	0.68	-0.432	0.02	0.48	-0.275	0.13	0.04	-0.269	0.14
82	1988	0.76	0.34	-0.002	0.99	0.37	0.054	0.71	0.41	0.029	0.84	0.71	-0.042	0.77	0.57	-0.095	0.51	0.01	-0.116	0.43
82	1984	0.6	0.42	-0.066	0.6	0.49	0.038	0.76	0.49	-0.037	0.77	0.62	-0.144	0.25	0.6	-0.174	0.17	0	-0.002	0.99
83	2009		0.48			0.37			0.39			0.51			0.52			0.15		
83	2004	0.47	0.53	0.04	0.63	0.54	0.026	0.76	0.47	0.02	0.81	0.62	-0.005	0.95	0.63	0.025	0.76	0.21	-0.03	0.72
83	1998	0.44	0.51	0.017	0.84	0.53	-0.025	0.76	0.44	-0.073	0.38	0.64	-0.022	0.79	0.63	-0.026	0.75	0.21	-0.014	0.86
83	1994	0.4	0.61	-0.052	0.51	0.61	-0.065	0.42	0.54	-0.107	0.18	0.69	-0.101	0.2	0.73	-0.133	0.09	0.33	-0.005	0.95
83	1988	0.27	0.53	-0.095	0.25	0.54	-0.071	0.39	0.49	-0.061	0.46	0.64	0	1	0.63	-0.092	0.26	0.23	0.042	0.61
83	1984	0.38	0.49	-0.29	0	0.54	-0.187	0.01	0.5	-0.158	0.03	0.67	-0.215	0	0.64	-0.331	0	0.15	-0.383	0
84	2009		0.52			0.53			0.56			0.66			0.64			0.25		
84	2004																			
84	1998	0.74	0.39	-0.236	0.02	0.48	-0.222	0.03	0.49	-0.192	0.06	0.69	-0.084	0.41	0.61	-0.214	0.03	0.07	-0.16	0.11
84	1994	0.31	0.33	-0.12	0.26	0.4	-0.094	0.38	0.42	-0.094	0.38	0.63	-0.186	0.08	0.54	-0.177	0.09	0.02	-0.167	0.12
84	1988	0.37	0.3	0.043	0.68	0.35	-0.044	0.67	0.37	-0.014	0.89	0.6	0.008	0.94	0.49	-0.023	0.83	0.03	-0.004	0.97
84	1984	0.45	0.33	-0.094	0.31	0.42	-0.092	0.32	0.44	-0.056	0.55	0.64	-0.064	0.49	0.52	-0.093	0.31	0.07	-0.029	0.75
85	2009		0.5			0.49			0.46			0.63			0.62			0.25		
85	2004	0.51	0.43	-0.161	0.12	0.42	-0.116	0.26	0.39	-0.106	0.3	0.58	-0.118	0.25	0.57	-0.158	0.12	0.13	-0.058	0.58
85	1998	0.57	0.54	0.015	0.88	0.55	0.036	0.72	0.48	-0.013	0.9	0.61	0.096	0.35	0.62	0.023	0.82	0.35	0.124	0.22
85	1994	0.36	0.61	0.116	0.26	0.6	0.021	0.84	0.52	0.015	0.89	0.64	0.099	0.34	0.7	0.114	0.27	0.32	0.005	0.96
85	1988	0.65	0.62	-0.061	0.46	0.55	-0.134	0.1	0.47	-0.094	0.25	0.67	0.05	0.54	0.68	-0.021	0.8	0.45	0.046	0.57
85	1984	0.48	0.56	-0.064	0.43	0.55	-0.07	0.39	0.49	-0.074	0.36	0.7	-0.039	0.64	0.69	-0.081	0.32	0.23	0.076	0.35
86	2009		0.58			0.44			0.43			0.55			0.52			0.15		
86	2004	0.71	0.58	-0.394	0	0.51	-0.387	0	0.46	-0.391	0	0.58	-0.442	0	0.63	-0.414	0	0.28	-0.297	0

		i_{ba}	$\ln(1+CI_3)$			$\ln(1+CI_4)$			$\ln(1+CI_5)$			$\ln(1+CI_6)$			$\ln(1+CI_7)$			$\ln(1+CI_8)$		
PEPs	**inv**	**ba**	**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**	
		R^2	**R^2**	**r**	**Sign**	**R^2**	**r**	**Sign**	**R^2**	**r**	**Sign**	**R^2**	**r**	**Sign**	**R^2**	**R^2**	**Sign**	**R^2**	**r**	**Sign**
86	1998	0.68	0.57	-0.254	0.01	0.49	-0.261	0.01	0.44	-0.257	0.01	0.52	-0.246	0.02	0.61	-0.321	0	0.27	-0.141	0.17
86	1994	0.66	0.6	0.005	0.96	0.52	-0.019	0.86	0.46	-0.011	0.92	0.57	0.035	0.74	0.62	0.069	0.5	0.39	0.017	0.87
86	1988	0.66	0.52	-0.319	0	0.43	-0.299	0	0.35	-0.233	0.01	0.5	-0.233	0.01	0.49	-0.283	0	0.35	-0.209	0.01
86	1984	0.76	0.41	-0.236	0	0.36	-0.163	0.04	0.33	-0.128	0.12	0.5	-0.116	0.15	0.48	-0.215	0.01	0.14	-0.223	0.01
87	2009		0.36			0.39			0.4			0.55			0.46			0.24		
87	2004	0.47	0.54	-0.056	0.69	0.58	-0.217	0.12	0.54	-0.289	0.04	0.6	-0.155	0.27	0.63	-0.161	0.26	0.2	-0.034	0.81
87	1998	0.45	0.57	-0.144	0.25	0.57	-0.253	0.04	0.53	-0.225	0.07	0.63	-0.225	0.07	0.64	-0.232	0.06	0.28	-0.175	0.16
87	1994	0.43	0.65	0.017	0.89	0.63	-0.051	0.69	0.56	-0.051	0.69	0.64	-0.086	0.49	0.62	-0.014	0.91	0.4	0.029	0.82
87	1988	0.54	0.61	-0.23	0.03	0.61	-0.292	0.01	0.53	-0.254	0.02	0.64	-0.305	0	0.61	-0.281	0.01	0.36	-0.307	0
87	1984	0.63	0.56	-0.305	0	0.49	-0.355	0	0.43	-0.334	0	0.61	-0.395	0	0.58	-0.357	0	0.13	-0.294	0
88	2009		0.71			0.68			0.6			0.82			0.66			0.41		
88	2004	0.72	0.75	-0.382	0.01	0.66	-0.447	0	0.6	-0.383	0.01	0.82	-0.386	0.01	0.79	-0.352	0.02	0.44	-0.579	0
88	1998	0.79	0.72	-0.015	0.92	0.61	-0.295	0.04	0.54	-0.278	0.05	0.76	-0.166	0.25	0.76	-0.059	0.69	0.49	-0.049	0.74
88	1994	0.53	0.64	-0.225	0.11	0.57	-0.464	0	0.48	-0.438	0	0.67	-0.439	0	0.67	-0.272	0.05	0.29	-0.235	0.09
88	1988	0.81	0.59	-0.164	0.13	0.5	-0.328	0	0.4	-0.245	0.02	0.55	-0.216	0.04	0.61	-0.134	0.21	0.3	-0.351	0
88	1984	0.81	0.54	-0.214	0.04	0.4	-0.258	0.01	0.33	-0.202	0.06	0.44	-0.161	0.13	0.57	-0.223	0.03	0.3	-0.38	0
89	2009		0.63			0.59			0.55			0.62			0.66			0.23		
89	2004	0.5	0.69	-0.21	0.07	0.63	-0.343	0	0.55	-0.305	0.01	0.74	-0.224	0.06	0.74	-0.228	0.05	0.51	-0.222	0.06
89	1998	0.7	0.63	-0.071	0.53	0.54	-0.141	0.22	0.47	-0.127	0.27	0.67	-0.075	0.51	0.72	-0.08	0.49	0.42	-0.013	0.91
89	1994	0.57	0.69	-0.145	0.22	0.55	-0.083	0.48	0.48	-0.048	0.68	0.66	0.017	0.89	0.74	-0.122	0.3	0.39	-0.31	0.01
89	1988	0.75	0.71	-0.206	0.03	0.61	-0.261	0.01	0.51	-0.221	0.02	0.62	-0.222	0.02	0.75	-0.219	0.02	0.43	-0.269	0
89	1984	0.63	0.55	-0.136	0.14	0.44	-0.192	0.04	0.35	-0.201	0.03	0.5	-0.28	0	0.6	-0.219	0.02	0.2	-0.17	0.07
90	2009		0.48			0.58			0.52			0.7			0.6			0.3		
90	2004	0.31	0.47	-0.056	0.6	0.57	-0.013	0.9	0.5	-0.058	0.58	0.68	-0.001	0.99	0.6	-0.066	0.53	0.36	0.164	0.12
90	1998	0.59	0.59	-0.145	0.17	0.65	-0.042	0.69	0.55	-0.079	0.45	0.69	-0.036	0.73	0.66	-0.166	0.11	0.6	-0.05	0.63
90	1994	0.28	0.66	-0.016	0.87	0.67	-0.086	0.4	0.56	-0.063	0.54	0.73	-0.155	0.13	0.72	-0.073	0.48	0.55	-0.187	0.06
90	1988	0.42	0.7	-0.104	0.28	0.65	-0.123	0.2	0.53	-0.146	0.13	0.76	-0.108	0.26	0.75	-0.181	0.06	0.56	0.005	0.96
90	1984	0.48	0.63	-0.162	0.06	0.64	-0.029	0.74	0.55	-0.019	0.82	0.77	-0.019	0.82	0.71	-0.152	0.08	0.51	-0.152	0.07
91	2009		0.44			0.48			0.47			0.54			0.53			0.11		
91	2004	0.36	0.38	0.096	0.38	0.43	-0.117	0.28	0.43	-0.185	0.09	0.57	-0.19	0.08	0.52	-0.021	0.85	0.06	-0.009	0.93
91	1998	0.41	0.41	-0.138	0.19	0.42	-0.12	0.26	0.42	-0.145	0.17	0.61	-0.024	0.82	0.57	-0.119	0.26	0.07	-0.025	0.81
91	1994	0.22	0.34	0.143	0.22	0.42	-0.036	0.76	0.42	-0.103	0.38	0.56	-0.148	0.21	0.52	0.031	0.79	0.03	0.115	0.33
91	1988	0.45	0.39	-0.164	0.11	0.41	-0.09	0.39	0.39	-0.078	0.46	0.59	-0.059	0.57	0.52	-0.156	0.13	0.04	-0.068	0.51
91	1984	0.24	0.38	-0.179	0.08	0.42	-0.105	0.3	0.41	-0.094	0.36	0.6	-0.054	0.6	0.53	-0.169	0.1	0.05	-0.106	0.3

		i_{ba}	ln(1+CI_3)			ln(1+CI_4)			ln(1+CI_5)			ln(1+CI_6)			ln(1+CI_7)			ln(1+CI_8)		
PEPs	inv	ba	ba	Partial corr		ba	Partial corr		ba	Partial corr		ba	Partial corr		ba	Partial corr		ba	Partial corr	
		R^2	R^2	r	Sign	R^2	r	Sign	R^2	r	Sign	R^2	r	Sign	R^2	R^2	Sign	R^2	r	Sign
92	2009		0.43			0.4			0.4			0.59			0.55			0.05		
92	2004	0.45	0.51	-0.125	0.2	0.51	-0.044	0.66	0.5	-0.03	0.76	0.66	-0.167	0.09	0.63	-0.133	0.17	0.04	-0.154	0.11
92	1998	0.5	0.59	-0.012	0.9	0.56	-0.061	0.55	0.51	-0.087	0.39	0.65	-0.076	0.45	0.64	-0.074	0.47	0.14	-0.056	0.58
92	1994	0.46	0.62	-0.212	0.02	0.54	-0.269	0	0.48	-0.203	0.02	0.67	-0.183	0.04	0.62	-0.187	0.03	0.24	-0.258	0
92	1988	0.33	0.51	-0.381	0	0.47	-0.349	0	0.43	-0.338	0	0.6	-0.31	0	0.55	-0.382	0	0.17	-0.145	0.11
92	1984	0.5	0.57	-0.279	0	0.52	-0.295	0	0.46	-0.282	0	0.66	-0.328	0	0.58	-0.274	0	0.26	-0.162	0.04
93	2009		0.55			0.53			0.5			0.77			0.65			0.22		
93	2004	0.69	0.71	-0.069	0.66	0.69	-0.255	0.1	0.64	-0.255	0.09	0.86	-0.029	0.85	0.82	0.081	0.6	0.51	-0.217	0.16
93	1998	0.62	0.64	-0.004	0.98	0.66	-0.169	0.29	0.6	-0.077	0.63	0.85	-0.018	0.91	0.78	0.033	0.84	0.4	-0.187	0.24
93	1994	0.41	0.68	0.077	0.59	0.58	-0.234	0.1	0.53	-0.215	0.13	0.77	-0.291	0.04	0.73	0.003	0.98	0.39	-0.076	0.6
93	1988	0.65	0.77	0.094	0.48	0.7	0.092	0.49	0.66	0.035	0.79	0.8	-0.023	0.86	0.77	0.056	0.67	0.61	0	1
93	1984	0.56	0.73	-0.23	0.08	0.61	-0.361	0	0.58	-0.26	0.05	0.8	-0.274	0.03	0.74	-0.206	0.11	0.44	-0.284	0.03
94	2009		0.41			0.41			0.43			0.69			0.55			0.15		
94	2004	0.4	0.49	-0.066	0.48	0.51	-0.102	0.28	0.47	-0.156	0.1	0.76	-0.196	0.04	0.61	-0.127	0.18	0.21	-0.027	0.78
94	1998	0.05	0.52	0.005	0.96	0.52	0.007	0.95	0.45	0.02	0.86	0.77	-0.075	0.49	0.62	-0.024	0.82	0.23	0.007	0.95
94	1994	0.37	0.63	-0.048	0.61	0.58	0.001	0.99	0.53	0.006	0.95	0.8	-0.001	0.99	0.73	-0.047	0.62	0.35	0.05	0.59
94	1988	0.22	0.59	-0.084	0.35	0.61	-0.106	0.24	0.52	-0.151	0.09	0.75	-0.208	0.02	0.66	-0.143	0.11	0.37	-0.006	0.95
94	1984	0.53	0.69	-0.106	0.2	0.69	-0.106	0.2	0.6	-0.11	0.18	0.79	-0.165	0.04	0.74	-0.153	0.06	0.46	-0.062	0.45
95	2009		0.36			0.31			0.3			0.5			0.44			0.04		
95	2004	0.61	0.46	-0.211	0.08	0.52	-0.218	0.07	0.44	-0.19	0.12	0.55	-0.114	0.35	0.54	-0.21	0.08	0.16	-0.136	0.27
95	1998	0.4	0.41	-0.108	0.41	0.48	-0.149	0.25	0.41	-0.141	0.28	0.55	-0.107	0.41	0.5	-0.152	0.24	0.12	0.043	0.74
95	1994	0.46	0.55	-0.095	0.41	0.6	-0.095	0.41	0.55	-0.095	0.41	0.65	-0.102	0.38	0.62	-0.07	0.55	0.28	-0.134	0.25
95	1988	0.34	0.49	-0.275	0.01	0.56	-0.339	0	0.53	-0.32	0	0.61	-0.264	0.01	0.58	-0.282	0.01	0.24	-0.243	0.02
95	1984	0.58	0.4	-0.327	0	0.49	-0.368	0	0.5	-0.322	0	0.61	-0.245	0.01	0.52	-0.314	0	0.09	-0.219	0.02
96	2009		0.43			0.39			0.42			0.56			0.51			0.11		
96	2004	0.71	0.46	-0.334	0.04	0.56	-0.147	0.37	0.5	-0.132	0.42	0.58	-0.07	0.67	0.59	-0.275	0.09	0.19	-0.32	0.05
96	1998	0.62	0.5	-0.156	0.32	0.49	-0.072	0.65	0.45	-0.113	0.47	0.6	-0.007	0.97	0.56	-0.157	0.31	0.22	-0.156	0.32
96	1994	0.29	0.57	-0.041	0.78	0.51	-0.141	0.34	0.44	-0.103	0.49	0.59	-0.092	0.54	0.6	-0.072	0.63	0.37	-0.033	0.82
96	1988	0.68	0.58	-0.03	0.81	0.55	-0.097	0.43	0.51	-0.097	0.43	0.61	-0.063	0.61	0.65	-0.033	0.79	0.39	-0.048	0.7
96	1984	0.63	0.58	-0.075	0.53	0.55	-0.219	0.06	0.5	-0.188	0.11	0.62	-0.084	0.48	0.62	-0.115	0.33	0.38	-0.178	0.13
201_1	2009		0.76			0.74			0.68			0.79			0.74			0.44		
201_2	2009		0.73			0.72			0.66			0.78			0.7			0.36		
201_1	2004	0.58	0.79	-0.031	0.63	0.82	-0.089	0.16	0.79	-0.083	0.19	0.73	-0.09	0.16	0.74	-0.056	0.38	0.62	-0.1	0.11
201_2	2004	0.64	0.81	0.115	0.08	0.83	0.076	0.25	0.79	0.065	0.32	0.8	-0.01	0.88	0.79	0.107	0.1	0.71	0.022	0.74

		i_{ba}	ln(1+CI$_3$)			ln(1+CI$_4$)			ln(1+CI$_5$)			ln(1+CI$_6$)			ln(1+CI$_7$)			ln(1+CI$_8$)		
PEPs	**inv**	**ba**	**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**	
		R^2	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	R^2	**Sign**	R^2	**r**	**Sign**
201_1	1998	0.7	0.78	-0.039	0.48	0.83	-0.139	0.01	0.77	-0.127	0.02	0.75	-0.091	0.09	0.75	-0.038	0.48	0.64	-0.111	0.04
201_2	1998	0.74	0.78	-0.109	0.06	0.8	-0.138	0.02	0.75	-0.127	0.03	0.8	-0.113	0.05	0.75	-0.131	0.02	0.63	-0.158	0.01
201_1	1994	0.73	0.66	-0.335	0	0.61	-0.408	0	0.57	-0.369	0	0.7	-0.306	0	0.59	-0.343	0	0.47	-0.354	0
201_2	1994	0.73	0.6	-0.463	0	0.51	-0.472	0	0.47	-0.444	0	0.7	-0.398	0	0.53	-0.465	0	0.38	-0.444	0
206_1	2009		0.68			0.74			0.64			0.83			0.59			0.73		
206_2	2009		0.71			0.73			0.64			0.82			0.62			0.53		
206_1	2004	0.73	0.65	-0.203	0.01	0.71	-0.222	0	0.64	-0.172	0.03	0.73	-0.286	0	0.64	-0.223	0	0.65	-0.376	0
206_2	2004	0.7	0.68	-0.153	0.06	0.67	-0.2	0.01	0.63	-0.163	0.05	0.73	-0.173	0.03	0.64	-0.185	0.02	0.48	-0.214	0.01
206_1	1998	0.79	0.5	-0.115	0.11	0.61	-0.316	0	0.56	-0.242	0	0.7	-0.258	0	0.61	-0.189	0.01	0.53	-0.297	0
206_2	1998	0.73	0.52	-0.354	0	0.51	-0.432	0	0.5	-0.38	0	0.65	-0.311	0	0.47	-0.327	0	0.34	-0.273	0
Average		0.52	0.55	-0.129	0.32	0.55	-0.168	0.27	0.51	-0.161	0.28	0.66	-0.152	0.32	0.62	-0.151	0.27	0.29	-0.132	0.36
Share of significant cases					24.10%			39.10%			34.50%			34.50%			29.90%			28.70%

c). The influence of distance dependent competition indices combined with selection method SB 60, on periodic mean annual tree basal area increment.

		i_{ba}	ln(1+CI$_3$)			ln(1+CI$_4$)			ln(1+CI$_5$)			ln(1+CI$_6$)			ln(1+CI$_7$)			ln(1+CI$_8$)		
PEPs	inv	ba	ba	Partial corr		ba	Partial corr		ba	Partial corr		ba	Partial corr		ba	Partial corr		ba	Partial corr	
		R^2	R^2	r	Sign	R^2	r	Sign	R^2	r	Sign	R^2	r	Sign	R^2	r	Sign	R^2	r	Sign
81	2009																			
81	2004		0.62			0.83			0.83			0.85			0.73			0.32		
81	1998	0.17	0.57	-0.04	0.73	0.8	-0.059	0.61	0.83	-0.118	0.3	0.86	-0.083	0.47	0.73	-0.048	0.67	0.36	0.201	0.08
81	1994	0.25	0.74	-0.039	0.69	0.89	-0.156	0.11	0.86	-0.134	0.18	0.88	-0.176	0.07	0.79	-0.079	0.43	0.54	-0.096	0.33
81	1988	0.33	0.77	-0.221	0.03	0.89	-0.133	0.2	0.86	-0.097	0.36	0.89	-0.105	0.32	0.79	-0.154	0.14	0.5	-0.148	0.16
81	1984	0.47	0.79	-0.177	0.05	0.88	-0.225	0.01	0.82	-0.316	0	0.89	-0.39	0	0.75	-0.309	0	0.46	0.125	0.17
82	2009		0.27			0.5			0.52			0.64			0.45			0.01		
82	2004																			
82	1998	0.52	0.23	-0.532	0.01	0.47	-0.584	0	0.62	-0.659	0	0.83	-0.655	0	0.54	-0.619	0	0.05	-0.479	0.02
82	1994	0.21	0.3	-0.173	0.35	0.53	-0.225	0.22	0.65	-0.298	0.1	0.78	-0.452	0.01	0.58	-0.317	0.08	0.08	-0.347	0.06
82	1988	0.76	0.4	0.071	0.63	0.59	0.019	0.9	0.64	-0.064	0.66	0.73	-0.097	0.51	0.56	-0.056	0.7	0.01	-0.025	0.87
82	1984	0.6	0.7	0.048	0.7	0.8	0.01	0.93	0.76	-0.12	0.34	0.74	-0.195	0.12	0.71	-0.108	0.39	0.12	0.157	0.21
83	2009		0.75			0.37			0.5			0.66			0.53			0.18		
83	2004	0.47	0.73	0.062	0.45	0.9	-0.034	0.68	0.86	-0.024	0.77	0.8	0.009	0.91	0.75	0.025	0.77	0.27	0.1	0.23
83	1998	0.44	0.76	0.017	0.84	0.92	-0.071	0.39	0.9	-0.137	0.1	0.79	-0.078	0.35	0.82	-0.099	0.23	0.3	-0.016	0.85
83	1994	0.4	0.79	-0.057	0.47	0.92	-0.158	0.04	0.88	-0.202	0.01	0.81	-0.126	0.11	0.81	-0.172	0.03	0.32	0.112	0.16
83	1988	0.27	0.75	-0.261	0	0.91	-0.258	0	0.88	-0.215	0.01	0.77	-0.023	0.78	0.81	-0.225	0.01	0.27	0.031	0.71
83	1984	0.38	0.76	-0.111	0.13	0.9	-0.159	0.03	0.86	-0.19	0.01	0.78	-0.202	0.01	0.8	-0.167	0.02	0.23	-0.103	0.16
84	2009		0.68			0.61			0.71			0.72			0.67			0.2		
84	2004																			
84	1998	0.74	0.67	-0.079	0.44	0.86	-0.025	0.8	0.86	-0.039	0.7	0.82	0.011	0.91	0.78	-0.053	0.6	0.15	0.044	0.66
84	1994	0.31	0.66	-0.143	0.18	0.84	-0.259	0.01	0.83	-0.323	0	0.76	-0.262	0.01	0.76	-0.262	0.01	0.12	-0.072	0.5
84	1988	0.37	0.69	-0.045	0.66	0.86	-0.142	0.17	0.83	-0.186	0.07	0.76	0.107	0.3	0.75	-0.108	0.3	0.12	0.116	0.26
84	1984	0.45	0.69	-0.075	0.42	0.85	-0.057	0.53	0.83	-0.08	0.39	0.77	-0.068	0.46	0.76	-0.08	0.38	0.16	0.127	0.17
85	2009		0.73			0.68			0.77			0.73			0.74			0.36		
85	2004	0.51	0.63	-0.233	0.02	0.8	-0.071	0.49	0.78	-0.063	0.54	0.7	-0.129	0.21	0.68	-0.176	0.09	0.15	-0.121	0.24
85	1998	0.57	0.66	-0.077	0.45	0.87	-0.046	0.65	0.86	-0.074	0.47	0.81	0.158	0.12	0.74	-0.12	0.24	0.45	0.096	0.35
85	1994	0.36	0.74	0.168	0.1	0.87	0.178	0.08	0.87	0.215	0.03	0.76	0.209	0.04	0.8	0.206	0.04	0.37	0.092	0.37
85	1988	0.65	0.74	-0.009	0.91	0.9	0.076	0.36	0.87	0.065	0.43	0.82	0.147	0.07	0.78	-0.022	0.79	0.41	0.114	0.17
85	1984	0.48	0.72	-0.138	0.09	0.88	-0.114	0.16	0.83	-0.103	0.21	0.81	-0.004	0.96	0.73	-0.143	0.08	0.26	0.13	0.11
86	2009		0.79			0.62			0.63			0.65			0.6			0.19		
86	2004	0.71	0.82	-0.207	0.05	0.88	-0.262	0.01	0.82	-0.293	0.01	0.7	-0.469	0	0.76	-0.271	0.01	0.5	-0.233	0.03

		i_{ba}	$\ln(1+CI_3)$			$\ln(1+CI_4)$			$\ln(1+CI_5)$			$\ln(1+CI_6)$			$\ln(1+CI_7)$			$\ln(1+CI_8)$		
PEPs	**inv**	**ba**	**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**	
		R^2	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**
86	1998	0.68	0.82	-0.176	0.08	0.86	-0.212	0.04	0.81	-0.309	0	0.65	-0.32	0	0.77	-0.318	0	0.53	-0.111	0.28
86	1994	0.66	0.8	0.095	0.36	0.87	0.151	0.14	0.8	0.166	0.11	0.68	0.091	0.38	0.75	0.171	0.1	0.49	-0.019	0.85
86	1988	0.66	0.78	-0.272	0	0.87	-0.305	0	0.76	-0.262	0	0.64	-0.299	0	0.66	-0.257	0	0.65	-0.189	0.02
86	1984	0.76	0.77	-0.202	0.01	0.85	-0.154	0.06	0.73	-0.162	0.05	0.63	-0.143	0.08	0.65	-0.205	0.01	0.51	-0.27	0
87	2009		0.77			0.64			0.68			0.68			0.62			0.26		
87	2004	0.47	0.8	-0.028	0.84	0.86	-0.135	0.34	0.82	-0.176	0.21	0.79	-0.126	0.37	0.75	-0.145	0.31	0.52	-0.057	0.69
87	1998	0.45	0.73	-0.276	0.03	0.88	-0.308	0.01	0.84	-0.261	0.04	0.8	-0.109	0.39	0.75	-0.274	0.03	0.63	0.077	0.54
87	1994	0.43	0.8	0.166	0.19	0.87	0.03	0.81	0.8	-0.022	0.86	0.79	-0.121	0.34	0.74	0.049	0.7	0.72	-0.159	0.2
87	1988	0.54	0.77	-0.165	0.13	0.86	-0.245	0.02	0.79	-0.288	0.01	0.79	-0.227	0.03	0.74	-0.26	0.01	0.72	0.216	0.04
87	1984	0.63	0.75	-0.236	0.02	0.84	-0.265	0.01	0.76	-0.304	0	0.75	-0.371	0	0.69	-0.286	0.01	0.5	-0.263	0.01
88	2009		0.88			0.81			0.79			0.88			0.72			0.48		
88	2004	0.72	0.91	-0.155	0.31	0.94	-0.112	0.46	0.9	-0.148	0.33	0.9	-0.446	0	0.87	-0.14	0.36	0.45	-0.417	0
88	1998	0.79	0.89	0.048	0.74	0.95	0.116	0.42	0.93	0.02	0.89	0.89	-0.259	0.07	0.9	-0.086	0.55	0.68	0.085	0.56
88	1994	0.53	0.88	-0.212	0.13	0.92	-0.132	0.35	0.87	-0.194	0.17	0.82	-0.456	0	0.85	-0.248	0.08	0.45	-0.41	0
88	1988	0.81	0.84	0.044	0.68	0.89	0.087	0.42	0.83	0.066	0.54	0.76	-0.178	0.1	0.78	0.059	0.58	0.43	-0.339	0
88	1984	0.81	0.81	-0.005	0.97	0.9	-0.011	0.92	0.85	-0.032	0.76	0.75	-0.179	0.09	0.78	-0.036	0.74	0.58	-0.267	0.01
89	2009		0.87			0.77			0.78			0.74			0.73			0.33		
89	2004	0.5	0.86	-0.036	0.76	0.91	-0.041	0.73	0.89	-0.108	0.36	0.84	-0.176	0.13	0.85	-0.115	0.33	0.56	-0.123	0.3
89	1998	0.7	0.83	-0.006	0.96	0.9	0.03	0.8	0.87	-0.007	0.95	0.82	-0.191	0.09	0.82	-0.016	0.89	0.6	-0.048	0.68
89	1994	0.57	0.83	-0.07	0.55	0.89	-0.009	0.94	0.87	0.028	0.82	0.8	-0.012	0.92	0.84	0.002	0.99	0.55	-0.032	0.79
89	1988	0.75	0.83	-0.162	0.09	0.87	-0.206	0.03	0.85	-0.187	0.05	0.77	-0.197	0.04	0.83	-0.16	0.1	0.45	-0.188	0.05
89	1984	0.63	0.81	-0.096	0.3	0.87	-0.131	0.16	0.84	-0.232	0.01	0.71	-0.285	0	0.81	-0.215	0.02	0.42	-0.051	0.59
90	2009		0.8			0.75			0.76			0.8			0.68			0.39		
90	2004	0.31	0.78	-0.045	0.67	0.91	0.09	0.39	0.87	-0.006	0.96	0.81	-0.019	0.86	0.75	-0.074	0.48	0.41	0.31	0
90	1998	0.59	0.77	-0.192	0.06	0.92	-0.195	0.06	0.88	-0.193	0.06	0.84	0	1	0.81	-0.22	0.03	0.61	0.208	0.05
90	1994	0.28	0.77	-0.051	0.62	0.91	-0.151	0.14	0.89	-0.148	0.14	0.85	-0.102	0.31	0.82	-0.077	0.45	0.51	-0.067	0.51
90	1988	0.42	0.77	-0.217	0.02	0.9	-0.225	0.02	0.88	-0.249	0.01	0.88	-0.106	0.27	0.82	-0.26	0.01	0.66	0.143	0.13
90	1984	0.48	0.77	-0.121	0.16	0.89	-0.073	0.39	0.87	-0.101	0.24	0.89	0.059	0.49	0.81	-0.099	0.25	0.71	-0.009	0.91
91	2009		0.68			0.73			0.69			0.67			0.65			0.26		
91	2004	0.36	0.67	0.126	0.25	0.86	0.106	0.33	0.83	-0.009	0.94	0.68	-0.152	0.16	0.76	-0.03	0.78	0.15	0.06	0.58
91	1998	0.41	0.67	-0.103	0.34	0.87	-0.062	0.56	0.84	-0.089	0.4	0.73	0.027	0.8	0.76	-0.072	0.5	0.12	-0.071	0.51
91	1994	0.22	0.59	0.159	0.17	0.83	-0.067	0.57	0.8	-0.223	0.05	0.7	-0.171	0.14	0.72	-0.098	0.4	0.12	0.248	0.03
91	1988	0.45	0.65	-0.132	0.21	0.85	-0.08	0.45	0.8	-0.104	0.32	0.72	-0.034	0.74	0.71	-0.12	0.25	0.11	-0.094	0.37
91	1984	0.24	0.66	-0.116	0.25	0.83	0.011	0.91	0.78	-0.037	0.72	0.73	0.016	0.88	0.71	-0.125	0.22	0.12	0.12	0.24

		i_{ba}	ln(1+CI_3)			ln(1+CI_4)			ln(1+CI_5)			ln(1+CI_6)			ln(1+CI_7)			ln(1+CI_8)		
PEPs	**inv**	**ba**	**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**	
		R^2	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**
92	2009		0.72			0.64			0.7			0.77			0.69			0.1		
92	2004	0.45	0.7	0.012	0.9	0.82	-0.079	0.42	0.82	-0.094	0.34	0.81	-0.146	0.13	0.76	-0.01	0.92	0.07	0.012	0.9
92	1998	0.5	0.75	-0.183	0.07	0.85	-0.254	0.01	0.82	-0.21	0.04	0.79	-0.105	0.3	0.76	-0.183	0.07	0.09	-0.102	0.32
92	1994	0.46	0.76	-0.078	0.38	0.86	-0.14	0.12	0.78	-0.159	0.07	0.8	-0.219	0.01	0.71	-0.135	0.13	0.16	-0.267	0
92	1988	0.33	0.75	-0.336	0	0.88	-0.399	0	0.8	-0.391	0	0.77	-0.293	0	0.72	-0.355	0	0.28	-0.101	0.26
92	1984	0.5	0.73	-0.127	0.11	0.86	-0.204	0.01	0.75	-0.224	0	0.78	-0.387	0	0.68	-0.21	0.01	0.31	-0.033	0.68
93	2009		0.78			0.7			0.77			0.83			0.72			0.22		
93	2004	0.69	0.75	0.002	0.99	0.9	0.107	0.49	0.9	0.296	0.05	0.9	0.097	0.53	0.83	0.241	0.12	0.56	-0.264	0.08
93	1998	0.62	0.68	0.039	0.81	0.87	0.183	0.25	0.91	0.238	0.13	0.9	-0.023	0.89	0.84	0.103	0.52	0.55	-0.224	0.16
93	1994	0.41	0.75	0.079	0.58	0.88	0.036	0.8	0.9	-0.024	0.87	0.88	-0.242	0.09	0.82	-0.006	0.97	0.66	-0.064	0.66
93	1988	0.65	0.83	-0.049	0.71	0.87	-0.059	0.66	0.86	-0.033	0.8	0.9	-0.016	0.9	0.83	-0.076	0.57	0.68	-0.133	0.31
93	1984	0.56	0.77	-0.197	0.13	0.77	-0.115	0.38	0.77	-0.13	0.32	0.87	-0.322	0.01	0.75	-0.162	0.22	0.47	-0.428	0
94	2009		0.76			0.67			0.72			0.8			0.66			0.24		
94	2004	0.4	0.72	-0.049	0.6	0.85	-0.092	0.33	0.84	-0.151	0.11	0.88	-0.148	0.12	0.76	-0.131	0.17	0.34	0.079	0.4
94	1998	0.05	0.72	0.081	0.45	0.87	-0.011	0.92	0.87	-0.04	0.71	0.86	-0.058	0.59	0.8	0.008	0.94	0.34	0.068	0.53
94	1994	0.37	0.7	0.01	0.91	0.85	-0.017	0.85	0.88	0.003	0.98	0.9	0.037	0.7	0.82	-0.002	0.99	0.4	0.051	0.59
94	1988	0.22	0.68	-0.098	0.27	0.82	-0.104	0.25	0.84	-0.169	0.06	0.85	-0.253	0	0.78	-0.19	0.03	0.4	-0.017	0.85
94	1984	0.53	0.7	-0.172	0.04	0.82	-0.182	0.03	0.84	-0.219	0.01	0.87	-0.176	0.03	0.78	-0.21	0.01	0.49	-0.093	0.26
95	2009		0.71			0.53			0.59			0.7			0.56			0.24		
95	2004	0.61	0.65	-0.234	0.05	0.83	-0.246	0.04	0.81	-0.237	0.05	0.75	-0.174	0.15	0.7	-0.255	0.03	0.36	-0.22	0.07
95	1998	0.4	0.59	-0.176	0.18	0.8	-0.18	0.17	0.77	-0.268	0.04	0.71	-0.154	0.24	0.64	-0.296	0.02	0.26	-0.031	0.81
95	1994	0.46	0.7	0.019	0.87	0.83	0.032	0.78	0.81	-0.034	0.77	0.77	-0.107	0.36	0.74	-0.011	0.93	0.4	-0.098	0.4
95	1988	0.34	0.61	-0.08	0.45	0.78	-0.029	0.78	0.76	-0.08	0.44	0.75	-0.299	0	0.68	-0.107	0.31	0.37	-0.148	0.16
95	1984	0.58	0.67	-0.238	0.01	0.77	-0.148	0.12	0.78	-0.17	0.07	0.75	-0.208	0.03	0.76	-0.239	0.01	0.33	-0.201	0.03
96	2009		0.69			0.71			0.72			0.65			0.65			0.09		
96	2004	0.71	0.55	-0.292	0.07	0.78	-0.137	0.4	0.77	-0.066	0.69	0.66	0.052	0.75	0.65	-0.146	0.38	0.08	-0.044	0.79
96	1998	0.62	0.57	-0.242	0.12	0.76	-0.277	0.07	0.71	-0.195	0.21	0.69	0.047	0.76	0.61	-0.178	0.25	0.21	-0.085	0.59
96	1994	0.29	0.57	-0.048	0.75	0.7	-0.05	0.74	0.72	-0.031	0.84	0.73	-0.016	0.92	0.63	-0.069	0.64	0.37	0.126	0.4
96	1988	0.68	0.68	-0.169	0.16	0.76	-0.175	0.15	0.73	-0.139	0.26	0.79	-0.123	0.31	0.65	-0.146	0.23	0.45	-0.174	0.15
96	1984	0.63	0.62	-0.009	0.94	0.72	-0.047	0.69	0.75	-0.086	0.47	0.81	0.025	0.83	0.64	-0.055	0.64	0.53	0.031	0.79
201_1	2009		0.84			0.85			0.81			0.86			0.76			0.55		
201_2	2009		0.84			0.84			0.8			0.84			0.73			0.38		
201_1	2004	0.58	0.82	-0.041	0.52	0.77	-0.066	0.3	0.77	-0.074	0.25	0.76	-0.091	0.15	0.74	-0.077	0.23	0.58	-0.125	0.05
201_2	2004	0.64	0.83	0.153	0.02	0.86	0.099	0.13	0.85	0.09	0.17	0.83	-0.012	0.85	0.79	0.144	0.03	0.57	0.046	0.48

PEPs	inv	i_{ba}	$\ln(1+CI_3)$			$\ln(1+CI_4)$			$\ln(1+CI_5)$			$\ln(1+CI_6)$			$\ln(1+CI_7)$			$\ln(1+CI_8)$		
		ba	**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**	
		R^2	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**
201_1	1998	0.7	0.76	-0.013	0.81	0.82	-0.019	0.72	0.81	-0.08	0.14	0.77	-0.094	0.08	0.69	-0.008	0.88	0.43	-0.099	0.07
201_2	1998	0.74	0.76	-0.084	0.15	0.78	-0.11	0.06	0.77	-0.109	0.06	0.82	-0.126	0.03	0.69	-0.104	0.07	0.41	-0.106	0.07
201_1	1994	0.73	0.6	-0.33	0	0.38	-0.36	0	0.38	-0.37	0	0.7	-0.317	0	0.47	-0.325	0	0.21	-0.308	0
201_2	1994	0.73	0.49	-0.446	0	0.22	-0.425	0	0.25	-0.426	0	0.68	-0.421	0	0.35	-0.428	0	0.13	-0.393	0
206_1	2009		0.67			0.76			0.65			0.86			0.57			0.49		
206_2	2009		0.72			0.77			0.68			0.85			0.6			0.42		
206_1	2004	0.73	0.58	-0.132	0.1	0.62	-0.235	0	0.58	-0.187	0.02	0.75	-0.297	0	0.56	-0.153	0.05	0.28	-0.187	0.02
206_2	2004	0.7	0.63	-0.167	0.04	0.58	-0.23	0	0.59	-0.236	0	0.74	-0.192	0.02	0.57	-0.203	0.01	0.25	-0.237	0
206_1	1998	0.79	0.39	-0.156	0.03	0.24	-0.312	0	0.34	-0.293	0	0.66	-0.305	0	0.43	-0.252	0	0.11	-0.331	0
206_2	1998	0.73	0.37	-0.406	0	0.21	-0.435	0	0.29	-0.413	0	0.63	-0.364	0	0.28	-0.383	0	0.08	-0.371	0
Average		0.52	0.71	-0.102	0.35	0.79	-0.114	0.33	0.78	-0.135	0.28	0.78	-0.147	0.29	0.71	-0.134	0.29	0.36	-0.073	0.31
Share of significant cases					19.50%			28.70%			29.90%			33.30%			32.20%			21.80%

(d). The influence of distance dependent competition indices combined with selection method HWCW 60, on periodic mean annual tree basal area increment.

		i_{ba}	$\ln(1+CI_3)$			$\ln(1+CI_4)$			$\ln(1+CI_5)$			$\ln(1+CI_6)$			$\ln(1+CI_7)$			$\ln(1+CI_8)$		
PEPs	**inv**	**ba**	**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**	
		R^2	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**
81	2009																			
81	2004		0.45			0.37			0.3			0.53			0.5			0.31		
81	1998	0.17	0.39	-0.263	0.02	0.29	-0.198	0.08	0.21	-0.154	0.18	0.45	-0.201	0.08	0.42	-0.263	0.02	0.27	-0.244	0.03
81	1994	0.25	0.44	0.001	0.99	0.4	0.03	0.76	0.31	0.025	0.8	0.55	-0.082	0.41	0.49	-0.013	0.89	0.3	-0.089	0.37
81	1988	0.33	0.48	-0.063	0.55	0.39	-0.116	0.27	0.31	-0.119	0.26	0.57	-0.027	0.79	0.51	-0.077	0.46	0.4	-0.017	0.87
81	1984	0.47	0.48	-0.278	0	0.44	-0.313	0	0.34	-0.258	0	0.57	-0.364	0	0.49	-0.308	0	0.37	-0.161	0.08
82	2009		0.28			0.36			0.35			0.45			0.35			0.11		
82	2004																			
82	1998	0.52	0.32	-0.365	0.08	0.34	-0.36	0.08	0.29	-0.303	0.15	0.47	-0.509	0.01	0.37	-0.409	0.05	0.04	-0.362	0.08
82	1994	0.21	0.28	-0.17	0.36	0.3	-0.395	0.03	0.28	-0.413	0.02	0.46	-0.342	0.06	0.39	-0.257	0.16	0.07	-0.105	0.57
82	1988	0.76	0.24	0.025	0.86	0.17	0.052	0.72	0.18	0.027	0.86	0.43	0.01	0.94	0.36	-0.019	0.9	0.13	0.016	0.91
82	1984	0.6	0.33	-0.132	0.29	0.24	-0.071	0.57	0.19	-0.085	0.5	0.42	-0.164	0.19	0.41	-0.165	0.19	0.14	-0.072	0.57
83	2009		0.31			0.2			0.17			0.31			0.32			0.21		
83	2004	0.47	0.29	0.032	0.7	0.25	-0.01	0.9	0.2	-0.024	0.77	0.34	0.008	0.92	0.33	0.013	0.88	0.22	0.036	0.66
83	1998	0.44	0.19	-0.044	0.6	0.16	-0.023	0.78	0.1	0.016	0.85	0.27	-0.091	0.28	0.23	-0.055	0.51	0.15	-0.042	0.62
83	1994	0.4	0.3	-0.153	0.05	0.22	-0.129	0.1	0.15	-0.11	0.16	0.4	-0.142	0.07	0.35	-0.162	0.04	0.19	-0.153	0.05
83	1988	0.27	0.32	-0.055	0.51	0.18	0.023	0.78	0.12	0.023	0.78	0.35	-0.044	0.59	0.35	-0.062	0.45	0.27	-0.039	0.64
83	1984	0.38	0.26	-0.087	0.23	0.17	-0.044	0.55	0.12	-0.024	0.74	0.31	-0.104	0.15	0.29	-0.098	0.18	0.18	-0.1	0.17
84	2009		0.45			0.38			0.33			0.53			0.5			0.31		
84	2004																			
84	1998	0.74	0.29	-0.193	0.05	0.25	-0.138	0.17	0.18	-0.112	0.27	0.45	-0.13	0.2	0.37	-0.192	0.06	0.17	-0.16	0.11
84	1994	0.31	0.26	-0.038	0.72	0.26	-0.003	0.98	0.19	0.038	0.72	0.41	-0.145	0.17	0.34	-0.067	0.53	0.14	-0.088	0.41
84	1988	0.37	0.16	0.044	0.67	0.17	0.077	0.46	0.13	0.123	0.24	0.28	0.006	0.95	0.21	0.021	0.84	0.09	0.037	0.72
84	1984	0.45	0.24	0.037	0.69	0.19	0.028	0.76	0.12	0.067	0.47	0.35	-0.035	0.71	0.3	0.043	0.64	0.16	0.027	0.77
85	2009		0.26			0.19			0.17			0.33			0.3			0.21		
85	2004	0.51	0.19	-0.05	0.63	0.1	-0.013	0.9	0.07	-0.007	0.94	0.25	-0.086	0.4	0.22	-0.06	0.56	0.15	-0.004	0.97
85	1998	0.57	0.22	-0.1	0.33	0.16	-0.085	0.41	0.12	-0.068	0.5	0.26	-0.045	0.66	0.25	-0.101	0.32	0.16	-0.092	0.37
85	1994	0.36	0.19	-0.023	0.82	0.14	-0.008	0.94	0.09	0.04	0.69	0.26	-0.029	0.78	0.21	-0.021	0.84	0.15	-0.036	0.73
85	1988	0.65	0.24	-0.081	0.32	0.17	-0.031	0.71	0.12	-0.029	0.73	0.31	-0.063	0.44	0.28	-0.091	0.27	0.17	-0.162	0.05
85	1984	0.48	0.3	-0.02	0.81	0.18	-0.033	0.69	0.14	-0.031	0.7	0.38	-0.075	0.36	0.34	-0.04	0.63	0.21	-0.058	0.48
86	2009		0.41			0.31			0.25			0.44			0.39			0.23		
86	2004	0.71	0.3	-0.28	0.01	0.25	-0.301	0	0.19	-0.256	0.01	0.39	-0.341	0	0.33	-0.289	0.01	0.14	-0.156	0.14

		i_{ba}	$\ln(1+CI_3)$			$\ln(1+CI_4)$			$\ln(1+CI_5)$			$\ln(1+CI_6)$			$\ln(1+CI_7)$			$\ln(1+CI_8)$		
PEPs	inv	ba	ba	Partial corr		ba	Partial corr		ba	Partial corr		ba	Partial corr		ba	Partial corr		ba	Partial corr	
		R^2	R^2	r	Sign	R^2	r	Sign	R^2	r	Sign	R^2	r	Sign	R^2	r	Sign	R^2	r	Sign
86	1998	0.68	0.32	-0.178	0.08	0.21	-0.214	0.03	0.14	-0.197	0.05	0.35	-0.217	0.03	0.35	-0.219	0.03	0.24	-0.154	0.13
86	1994	0.66	0.32	0.026	0.8	0.22	-0.007	0.95	0.15	0.03	0.77	0.37	0.004	0.97	0.34	0.043	0.68	0.28	0.026	0.8
86	1988	0.66	0.26	-0.197	0.02	0.18	-0.149	0.08	0.13	-0.126	0.14	0.28	-0.157	0.06	0.26	-0.173	0.04	0.22	-0.183	0.03
86	1984	0.76	0.26	-0.114	0.16	0.16	-0.07	0.39	0.13	-0.036	0.66	0.31	-0.112	0.17	0.29	-0.094	0.25	0.21	-0.092	0.26
87	2009		0.32			0.24			0.21			0.39			0.34			0.33		
87	2004	0.47	0.34	-0.206	0.14	0.23	-0.285	0.04	0.17	-0.246	0.08	0.48	-0.265	0.06	0.42	-0.259	0.06	0.4	-0.119	0.4
87	1998	0.45	0.36	-0.104	0.41	0.26	-0.123	0.33	0.21	-0.121	0.34	0.45	-0.21	0.09	0.41	-0.155	0.22	0.35	-0.071	0.57
87	1994	0.43	0.5	0.027	0.83	0.35	-0.032	0.8	0.28	-0.045	0.72	0.5	-0.095	0.45	0.48	-0.015	0.91	0.51	-0.023	0.86
87	1988	0.54	0.43	-0.226	0.04	0.28	-0.164	0.13	0.23	-0.178	0.1	0.44	-0.252	0.02	0.45	-0.264	0.01	0.39	-0.201	0.06
87	1984	0.63	0.32	-0.361	0	0.21	-0.249	0.02	0.15	-0.182	0.08	0.33	-0.337	0	0.33	-0.342	0	0.19	-0.361	0
88	2009		0.48			0.38			0.3			0.57			0.47			0.29		
88	2004	0.72	0.33	-0.357	0.02	0.28	-0.274	0.07	0.18	-0.199	0.19	0.42	-0.304	0.04	0.39	-0.327	0.03	0.18	-0.406	0.01
88	1998	0.79	0.43	-0.231	0.11	0.19	-0.084	0.56	0.13	-0.002	0.99	0.39	-0.228	0.11	0.42	-0.224	0.12	0.38	-0.358	0.01
88	1994	0.53	0.26	-0.42	0	0.17	-0.212	0.13	0.12	-0.135	0.34	0.28	-0.322	0.02	0.29	-0.405	0	0.14	-0.455	0
88	1988	0.81	0.26	-0.252	0.02	0.2	-0.076	0.48	0.15	-0.026	0.81	0.28	-0.187	0.08	0.28	-0.211	0.05	0.13	-0.366	0
88	1984	0.81	0.27	-0.239	0.02	0.18	-0.109	0.31	0.12	-0.057	0.6	0.21	-0.144	0.18	0.26	-0.213	0.04	0.2	-0.258	0.01
89	2009		0.49			0.35			0.3			0.5			0.51			0.4		
89	2004	0.5	0.42	-0.23	0.05	0.32	-0.224	0.05	0.26	-0.203	0.08	0.42	-0.235	0.04	0.42	-0.227	0.05	0.29	-0.175	0.14
89	1998	0.7	0.3	-0.125	0.28	0.24	-0.068	0.55	0.19	-0.041	0.72	0.34	-0.117	0.31	0.33	-0.111	0.34	0.18	-0.197	0.08
89	1994	0.57	0.33	-0.016	0.89	0.27	-0.082	0.49	0.21	-0.095	0.42	0.37	0.025	0.83	0.36	-0.029	0.81	0.23	0.034	0.77
89	1988	0.75	0.3	-0.138	0.15	0.19	-0.136	0.16	0.15	-0.112	0.25	0.34	-0.184	0.06	0.34	-0.138	0.15	0.22	-0.086	0.38
89	1984	0.63	0.17	-0.124	0.18	0.14	-0.109	0.24	0.11	-0.09	0.33	0.23	-0.212	0.02	0.21	-0.145	0.12	0.09	-0.108	0.24
90	2009		0.28			0.18			0.15			0.33			0.3			0.24		
90	2004	0.31	0.29	-0.057	0.59	0.12	-0.151	0.15	0.08	-0.154	0.14	0.37	-0.058	0.58	0.34	-0.061	0.56	0.27	0.046	0.66
90	1998	0.59	0.31	-0.08	0.45	0.17	-0.131	0.21	0.11	-0.115	0.27	0.39	-0.13	0.21	0.36	-0.119	0.26	0.33	-0.057	0.58
90	1994	0.28	0.34	0.072	0.48	0.23	-0.048	0.64	0.17	-0.051	0.62	0.44	-0.055	0.59	0.39	0.032	0.76	0.31	0.107	0.29
90	1988	0.42	0.34	-0.055	0.56	0.22	-0.176	0.06	0.17	-0.163	0.09	0.42	-0.046	0.63	0.38	-0.084	0.38	0.33	0.053	0.58
90	1984	0.48	0.34	-0.073	0.39	0.25	-0.047	0.58	0.2	-0.048	0.58	0.45	-0.047	0.58	0.4	-0.071	0.41	0.27	-0.061	0.48
91	2009		0.3			0.28			0.22			0.41			0.36			0.22		
91	2004	0.36	0.22	-0.141	0.2	0.26	-0.192	0.08	0.2	-0.159	0.14	0.35	-0.245	0.02	0.27	-0.169	0.12	0.1	-0.108	0.32
91	1998	0.41	0.21	-0.216	0.04	0.22	-0.152	0.15	0.17	-0.14	0.19	0.35	-0.138	0.19	0.27	-0.175	0.1	0.09	-0.235	0.03
91	1994	0.22	0.2	-0.031	0.79	0.21	-0.151	0.2	0.16	-0.192	0.1	0.34	-0.139	0.23	0.27	-0.086	0.46	0.11	-0.016	0.89
91	1988	0.45	0.2	-0.044	0.68	0.2	-0.08	0.44	0.15	-0.118	0.26	0.31	-0.054	0.61	0.24	-0.055	0.6	0.07	-0.053	0.61
91	1984	0.24	0.22	-0.083	0.42	0.21	-0.072	0.48	0.16	-0.1	0.33	0.35	-0.066	0.52	0.27	-0.084	0.41	0.11	0.01	0.92

		i_{ba}	$\ln(1+CI_3)$			$\ln(1+CI_4)$			$\ln(1+CI_5)$			$\ln(1+CI_6)$			$\ln(1+CI_7)$			$\ln(1+CI_8)$		
PEPs	**inv**	**ba**	**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**	
		R^2	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**
92	2009		0.3			0.23			0.18			0.35			0.33			0.13		
92	2004	0.45	0.33	-0.013	0.89	0.24	-0.075	0.45	0.16	-0.049	0.62	0.4	-0.053	0.59	0.38	-0.005	0.96	0.21	0.119	0.22
92	1998	0.5	0.37	-0.141	0.16	0.28	-0.058	0.57	0.16	-0.012	0.91	0.41	-0.121	0.23	0.41	-0.131	0.2	0.21	-0.212	0.04
92	1994	0.46	0.4	-0.119	0.18	0.3	-0.088	0.32	0.23	-0.075	0.4	0.43	-0.178	0.04	0.41	-0.141	0.11	0.32	-0.159	0.07
92	1988	0.33	0.31	-0.339	0	0.25	-0.272	0	0.17	-0.216	0.02	0.35	-0.326	0	0.33	-0.331	0	0.24	-0.353	0
92	1984	0.5	0.43	-0.297	0	0.32	-0.275	0	0.24	-0.214	0.01	0.43	-0.299	0	0.41	-0.267	0	0.33	-0.251	0
93	2009		0.34			0.27			0.23			0.43			0.35			0.16		
93	2004	0.69	0.37	-0.232	0.13	0.36	-0.225	0.14	0.3	-0.135	0.38	0.53	-0.221	0.15	0.44	-0.172	0.26	0.25	-0.254	0.1
93	1998	0.62	0.29	-0.023	0.88	0.36	0.069	0.67	0.3	0.055	0.73	0.48	0.022	0.89	0.38	-0.021	0.9	0.17	-0.236	0.14
93	1994	0.41	0.36	-0.098	0.5	0.32	-0.102	0.48	0.25	-0.065	0.66	0.43	-0.19	0.19	0.38	-0.121	0.4	0.22	-0.172	0.23
93	1988	0.65	0.5	0.105	0.43	0.44	-0.068	0.61	0.34	-0.073	0.58	0.53	-0.08	0.55	0.52	0.066	0.62	0.33	0.068	0.61
93	1984	0.56	0.49	-0.207	0.11	0.45	-0.093	0.48	0.34	-0.034	0.79	0.53	-0.208	0.11	0.51	-0.182	0.16	0.22	-0.283	0.03
94	2009		0.2			0.23			0.23			0.41			0.3			0.07		
94	2004	0.4	0.2	-0.159	0.09	0.21	-0.127	0.18	0.19	-0.084	0.37	0.4	-0.25	0.01	0.26	-0.182	0.05	0.09	-0.179	0.06
94	1998	0.05	0.2	0.038	0.73	0.2	0.037	0.73	0.19	-0.017	0.87	0.42	0.015	0.89	0.27	0.024	0.82	0.08	0.002	0.99
94	1994	0.37	0.27	0.072	0.44	0.24	-0.008	0.93	0.22	-0.025	0.79	0.48	0.021	0.83	0.35	0.069	0.47	0.13	0.113	0.23
94	1988	0.22	0.23	-0.031	0.73	0.2	-0.055	0.54	0.16	-0.036	0.69	0.38	-0.159	0.08	0.28	-0.072	0.42	0.1	-0.027	0.76
94	1984	0.53	0.39	-0.086	0.29	0.25	-0.038	0.65	0.2	-0.067	0.41	0.5	-0.142	0.08	0.43	-0.109	0.18	0.26	-0.119	0.15
95	2009		0.22			0.1			0.08			0.22			0.24			0.18		
95	2004	0.61	0.29	-0.189	0.12	0.12	-0.076	0.53	0.09	-0.036	0.77	0.25	-0.177	0.15	0.3	-0.206	0.09	0.24	-0.225	0.06
95	1998	0.4	0.21	-0.144	0.27	0.12	-0.082	0.53	0.09	-0.068	0.6	0.21	-0.125	0.34	0.22	-0.166	0.2	0.17	-0.166	0.2
95	1994	0.46	0.35	-0.088	0.45	0.24	-0.069	0.55	0.19	-0.04	0.73	0.35	-0.07	0.55	0.37	-0.082	0.48	0.27	-0.15	0.2
95	1988	0.34	0.37	-0.288	0.01	0.24	-0.226	0.03	0.17	-0.16	0.13	0.37	-0.219	0.03	0.39	-0.268	0.01	0.29	-0.294	0
95	1984	0.58	0.39	-0.295	0	0.31	-0.23	0.01	0.24	-0.164	0.08	0.42	-0.241	0.01	0.43	-0.292	0	0.28	-0.285	0
96	2009		0.42			0.32			0.24			0.42			0.45			0.38		
96	2004	0.71	0.41	-0.15	0.36	0.27	-0.171	0.3	0.2	-0.107	0.52	0.41	-0.103	0.53	0.44	-0.122	0.46	0.36	-0.118	0.48
96	1998	0.62	0.27	-0.103	0.51	0.23	-0.197	0.21	0.17	-0.134	0.39	0.42	0.062	0.69	0.3	-0.104	0.51	0.17	-0.111	0.48
96	1994	0.29	0.3	0.033	0.83	0.25	0.121	0.42	0.19	0.058	0.7	0.38	-0.086	0.57	0.33	0.016	0.92	0.22	-0.003	0.98
96	1988	0.68	0.38	-0.14	0.25	0.28	-0.069	0.57	0.23	-0.036	0.77	0.46	-0.077	0.53	0.4	-0.119	0.33	0.27	-0.174	0.15
96	1984	0.63	0.37	-0.229	0.05	0.34	-0.084	0.48	0.28	-0.011	0.93	0.44	-0.127	0.28	0.37	-0.22	0.06	0.28	-0.35	0
201_1	2009		0.55			0.43			0.33			0.61			0.56			0.38		
201_2	2009		0.53			0.4			0.32			0.61			0.55			0.35		
201_1	2004	0.58	0.66	-0.033	0.6	0.52	-0.025	0.69	0.4	-0.022	0.73	0.61	-0.078	0.22	0.62	-0.046	0.47	0.5	-0.106	0.09
201_2	2004	0.64	0.65	0.104	0.11	0.51	0.028	0.67	0.39	0.013	0.84	0.67	0.012	0.85	0.62	0.096	0.14	0.43	0.089	0.17

		i_{ba}	ln(1+CI_3)			ln(1+CI_4)			ln(1+CI_5)			ln(1+CI_6)			ln(1+CI_7)			ln(1+CI_8)		
PEPs	**inv**	**ba**	**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**		**ba**	**Partial corr**	
		R^2	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**
201_1	1998	0.7	0.59	-0.11	0.04	0.49	-0.055	0.31	0.38	-0.028	0.6	0.61	-0.068	0.21	0.55	-0.113	0.04	0.42	-0.151	0.01
201_2	1998	0.74	0.53	-0.133	0.02	0.46	-0.076	0.19	0.37	-0.053	0.36	0.65	-0.096	0.1	0.48	-0.145	0.01	0.32	-0.17	0
201_1	1994	0.73	0.39	-0.3	0	0.3	-0.219	0	0.25	-0.168	0	0.48	-0.26	0	0.34	-0.306	0	0.25	-0.349	0
201_2	1994	0.73	0.29	-0.356	0	0.24	-0.315	0	0.19	-0.245	0	0.4	-0.348	0	0.25	-0.353	0	0.16	-0.379	0
206_1	2009		0.63			0.57			0.45			0.73			0.56			0.57		
206_2	2009		0.6			0.58			0.49			0.72			0.55			0.48		
206_1	2004	0.73	0.54	-0.127	0.11	0.46	-0.121	0.13	0.38	-0.09	0.25	0.6	-0.197	0.01	0.53	-0.132	0.09	0.53	-0.179	0.02
206_2	2004	0.7	0.5	-0.139	0.09	0.51	-0.123	0.13	0.44	-0.091	0.26	0.61	-0.129	0.12	0.48	-0.15	0.07	0.29	-0.173	0.03
206_1	1998	0.79	0.39	-0.171	0.02	0.38	-0.225	0	0.34	-0.146	0.04	0.5	-0.245	0	0.44	-0.241	0	0.37	-0.336	0
206_2	1998	0.73	0.39	-0.342	0	0.33	-0.318	0	0.27	-0.221	0	0.51	-0.335	0	0.35	-0.329	0	0.23	-0.337	0
Average		0.52	0.34	-0.128	0.33	0.27	-0.113	0.38	0.21	-0.089	0.44	0.42	-0.145	0.31	0.37	-0.137	0.31	0.24	-0.136	0.31
Share of significant cases					26.40%			16.10%			10.30%			25.30%			26.40%			28.70%

(e). The influence of distance independent competition indices on periodic mean annual tree height increment.

PEPs	inv	i_h	ln(1+CI$_1$)			ln(1+CI$_2$)			Plot	Inv.	i_h	ln(1+CI$_1$)			ln(1+CI$_2$)		
		h	h	Partial corr		h	Partial corr				h	h	Partial corr		h	Partial corr	
		R^2	R^2	r	Sign	R^2	r	Sign			R^2	R^2	r	Sign	R^2	r	Sign
81	2009								90	2009		0.17			0.63		
81	2004		0.26			0.42			90	2004	0.05	0.47	-0.368	0.16	0.58	-0.542	0.03
81	1998	0.28	0.3	0.054	0.83	0.48	-0.034	0.89	90	1998	0.03	0.4	0.016	0.95	0.61	-0.373	0.1
81	1994	0	0.28	0.025	0.93	0.23	0.119	0.67	90	1994	0	0.57	0.058	0.83	0.66	0.102	0.71
81	1988	0	0.51	-0.043	0.86	0.66	-0.255	0.29	90	1988	0.02	0.68	0.311	0.22	0.88	-0.003	0.99
81	1984	0.01	0.42	0.017	0.94	0.37	-0.102	0.66	90	1984	0.45	0.52	-0.424	0.03	0.75	-0.209	0.3
82	2009		0.52			0.83			91	2009		0.19			0.4		
82	2004								91	2004	0.15	0.41	-0.371	0.17	0.68	-0.397	0.14
82	1998	0.64	0.49	0.152	0.72	0.68	0.066	0.88	91	1998	0.23	0.3	0.004	0.99	0.49	0.119	0.59
82	1994	0.13	0.53	-0.01	0.97	0.81	-0.3	0.24	91	1994	0.01	0.34	0.018	0.94	0.52	0.014	0.95
82	1988	0.13	0.4	-0.473	0.03	0.62	-0.523	0.02	91	1988	0.31	0.21	-0.652	0.01	0.13	-0.63	0.01
82	1984	0.28	0.48	-0.078	0.72	0.6	-0.265	0.22	91	1984	0.01	0.18	0.258	0.32	0.26	0.187	0.47
83	2009		0.27			0.48			92	2009		0.43			0.7		
83	2004	0.04	0.27	-0.141	0.46	0.41	-0.144	0.46	92	2004	0.01	0.66	-0.015	0.95	0.67	-0.169	0.44
83	1998	0.03	0.3	-0.153	0.42	0.49	-0.357	0.05	92	1998	0.16	0.51	-0.223	0.41	0.83	-0.133	0.62
83	1994	0	0.32	-0.281	0.18	0.72	-0.604	0	92	1994	0.05	0.54	0.22	0.28	0.76	0.217	0.29
83	1988	0	0.38	0.167	0.42	0.6	-0.05	0.81	92	1988	0	0.52	-0.376	0.05	0.7	-0.487	0.01
83	1984	0.06	0.28	-0.356	0.07	0.53	-0.41	0.03	92	1984	0	0.47	0.135	0.5	0.53	0.025	0.9
84	2009		0.37			0.66			93	2009		0.45			0.68		
84	2004								93	2004	0.02	0.45	-0.062	0.84	0.79	0.045	0.88
84	1998	0.06	0.54	-0.354	0.03	0.63	-0.296	0.08	93	1998	0.02	0.49	0.003	0.99	0.81	-0.246	0.47
84	1994	0.02	0.35	-0.274	0.18	0.47	-0.361	0.07	93	1994	0.09	0.55	0.037	0.9	0.82	0.089	0.76
84	1988	0.07	0.58	-0.41	0.03	0.57	-0.273	0.16	93	1988	0.09	0.68	-0.152	0.62	0.8	-0.31	0.3
84	1984	0	0.37	-0.23	0.22	0.5	-0.392	0.03	93	1984	0.19	0.61	-0.046	0.86	0.88	-0.631	0.01
85	2009		0.39			0.53			94	2009		0.43			0.73		
85	2004	0.01	0.46	-0.053	0.81	0.58	-0.413	0.05	94	2004	0.04	0.4	-0.459	0.03	0.65	-0.31	0.15
85	1998	0	0.51	-0.351	0.08	0.65	-0.271	0.18	94	1998	0.22	0.39	-0.213	0.47	0.58	-0.124	0.67
85	1994	0.02	0.43	-0.336	0.06	0.59	-0.523	0	94	1994	0	0.49	0.122	0.56	0.66	0.097	0.65
85	1988	0.01	0.5	-0.245	0.14	0.74	-0.27	0.11	94	1988	0.11	0.53	-0.084	0.69	0.73	-0.001	1
85	1984	0.05	0.5	0.119	0.46	0.67	-0.132	0.42	94	1984	0.01	0.38	-0.248	0.22	0.61	-0.278	0.17
86	2009		0.14			0.62			95	2009		0.43			0.64		
86	2004	0.16	0.55	0.205	0.37	0.79	0.026	0.91	95	2004	0	0.32	-0.412	0.06	0.61	-0.407	0.06

PEPs	inv	i_h	ln(1+CI_1)			ln(1+CI_2)		
		h	h	Partial corr		h	Partial corr	
		R^2	R^2	r	Sign	R^2	r	Sign
86	1998	0.26	0.57	-0.291	0.17	0.78	-0.404	0.05
86	1994	0.02	0.5	-0.425	0.05	0.66	-0.598	0
86	1988	0.1	0.51	-0.129	0.51	0.64	-0.141	0.47
86	1984	0	0.5	-0.215	0.3	0.7	-0.322	0.12
87	2009		0.25			0.69		
87	2004	0.26	0.55	0.625	0.03	0.76	0.386	0.21
87	1998	0.25	0.79	0.196	0.47	0.8	-0.191	0.48
87	1994	0	0.49	-0.009	0.97	0.68	-0.281	0.26
87	1988	0.39	0.71	-0.254	0.27	0.83	-0.121	0.6
87	1984	0.05	0.74	-0.201	0.36	0.81	-0.634	0
88	2009		0.24			0.81		
88	2004	0.09	0.36	-0.25	0.37	0.81	-0.54	0.04
88	1998	0.43	0.5	-0.046	0.87	0.86	-0.31	0.26
88	1994	0.26	0.62	0.32	0.21	0.74	-0.224	0.39
88	1988	0.18	0.51	-0.436	0.04	0.75	-0.532	0.01
88	1984	0.01	0.39	-0.451	0.03	0.38	-0.703	0
89	2009		0.15			0.7		
89	2004	0.2	0.53	-0.551	0	0.66	-0.5	0.01
89	1998	0	0.65	-0.017	0.94	0.66	-0.204	0.34
89	1994	0.09	0.61	-0.42	0.03	0.6	-0.397	0.04
89	1988	0.12	0.63	-0.18	0.37	0.6	-0.239	0.23
89	1984	0.01	0.56	-0.086	0.7	0.5	-0.166	0.45

Plot	Inv.	i_h	ln(1+CI_1)			ln(1+CI_2)		
		h	h	Partial corr		h	Partial corr	
		R^2	R^2	r	Sign	R^2	r	Sign
95	1998	0.08	0.34	-0.793	0	0.52	-0.211	0.49
95	1994	0.35	0.5	-0.007	0.98	0.82	0.005	0.98
95	1988	0.01	0.43	0.331	0.12	0.73	0.027	0.9
95	1984	0.15	0.47	-0.01	0.96	0.75	-0.009	0.97
96	2009		0.33			0.6		
96	2004	0	0.12	0.103	0.76	0.26	0.015	0.97
96	1998	0.17	0.27	-0.298	0.35	0.55	-0.455	0.14
96	1994	0.18	0.22	-0.414	0.16	0.3	-0.531	0.06
96	1988	0.4	0.55	-0.161	0.46	0.72	-0.303	0.16
96	1984	0.36	0.62	-0.213	0.34	0.77	-0.289	0.19
201_1	2009		0.37			0.63		
201_2	2009		0.54			0.65		
201_1	2004	0.18	0.35	-0.177	0.31	0.46	-0.481	0
201_2	2004	0.04	0.34	-0.399	0.05	0.34	-0.571	0
201_1	1998	0.06	0.12	-0.455	0	0.25	-0.51	0
201_2	1998	0.01	0.38	-0.411	0.02	0.43	-0.58	0
201_1	1994	0.25	0.32	0.004	0.98	0.66	-0.244	0.08
201_2	1994	0.12	0.54	-0.193	0.27	0.6	-0.376	0.03
206_1	2009		0.41			0.69		
206_2	2009		0.49			0.89		
206_1	2004	0.16	0.49	-0.05	0.83	0.58	-0.438	0.05
206_2	2004	0.64	0.5	0.131	0.51	0.83	-0.286	0.15
206_1	1998	0.07	0.35	-0.361	0.08	0.54	-0.751	0
206_2	1998	0.02	0.23	-0.701	0	0.58	-0.744	0
Average		0.12	0.44	-0.148	0.42	0.63	-0.264	0.32
Share of significant cases					18.40%			27.60%

(f). The influence of distance dependent competition indices combined with selection method HCB 80, on periodic mean annual tree height increment.

		i_h	$\ln(1+CI_3)$			$\ln(1+CI_4)$			$\ln(1+CI_5)$			$\ln(1+CI_6)$			$\ln(1+CI_7)$			$\ln(1+CI_8)$		
PEPs	inv	h	h	Partial corr		h	Partial corr		h	Partial corr		h	Partial corr		h	Partial corr		h	Partial corr	
		R^2	R^2	r	Sign	R^2	r	Sign	R^2	r	Sign	R^2	r	Sign	R^2	r	Sign	R^2	r	Sign
81	2009																			
81	2004		0.31			0.27			0.49			0.71			0.5			0.08		
81	1998	0.28	0.43	-0.091	0.72	0.26	0.162	0.52	0.44	-0.014	0.96	0.66	0.135	0.59	0.67	-0.224	0.37	0.17	0.267	0.28
81	1994	0	0.24	-0.063	0.82	0.2	0.221	0.43	0.39	0.329	0.23	0.52	-0.106	0.71	0.39	-0.234	0.4	0.03	-0.126	0.65
81	1988	0	0.58	-0.315	0.19	0.79	-0.151	0.54	0.84	-0.344	0.15	0.91	-0.417	0.08	0.72	-0.427	0.07	0.22	-0.229	0.35
81	1984	0.01	0.09	-0.276	0.23	0.36	-0.348	0.12	0.53	-0.426	0.05	0.64	-0.106	0.65	0.24	-0.237	0.3	0.02	-0.062	0.79
82	2009		0.44			0.61			0.73			0.77			0.63			0.06		
82	2004																			
82	1998	0.64	0.15	-0.278	0.5	0.39	-0.509	0.2	0.62	-0.414	0.31	0.92	-0.172	0.68	0.67	-0.394	0.33	0.2	-0.656	0.08
82	1994	0.13	0.06	0.097	0.71	0.17	0.09	0.73	0.32	-0.016	0.95	0.6	-0.101	0.7	0.29	0.007	0.98	0.03	0.197	0.45
82	1988	0.13	0.32	-0.373	0.1	0.36	-0.04	0.86	0.58	-0.153	0.51	0.88	-0.115	0.62	0.62	-0.524	0.01	0.07	0.281	0.22
82	1984	0.28	0.43	0.092	0.68	0.53	-0.028	0.9	0.61	-0.144	0.51	0.83	-0.229	0.29	0.63	-0.114	0.6	0.05	0.426	0.04
83	2009		0.51			0.38			0.52			0.59			0.49			0.29		
83	2004	0.04	0.29	-0.269	0.16	0.41	-0.366	0.05	0.53	-0.325	0.09	0.83	-0.019	0.92	0.54	-0.148	0.44	0.17	-0.354	0.06
83	1998	0.03	0.37	-0.049	0.8	0.43	-0.002	0.99	0.52	-0.03	0.87	0.87	-0.265	0.16	0.57	-0.304	0.1	0.19	0.148	0.43
83	1994	0	0.52	-0.239	0.26	0.63	-0.141	0.51	0.76	-0.11	0.61	0.92	-0.448	0.03	0.79	-0.444	0.03	0.3	-0.004	0.98
83	1988	0	0.43	-0.022	0.91	0.67	0.179	0.38	0.76	0.037	0.86	0.88	-0.217	0.29	0.62	-0.153	0.46	0.29	0.244	0.23
83	1984	0.06	0.27	-0.153	0.45	0.55	0.076	0.71	0.67	0.074	0.71	0.9	-0.209	0.3	0.55	-0.259	0.19	0.16	0.091	0.65
84	2009		0.48			0.45			0.63			0.71			0.56			0.39		
84	2004																			
84	1998	0.06	0.34	-0.265	0.11	0.41	-0.379	0.02	0.44	-0.328	0.05	0.76	-0.292	0.08	0.54	-0.323	0.05	0.2	-0.236	0.16
84	1994	0.02	0.4	-0.009	0.97	0.38	-0.187	0.36	0.39	-0.24	0.24	0.76	-0.375	0.06	0.59	-0.129	0.53	0.19	0.153	0.46
84	1988	0.07	0.22	0.016	0.94	0.31	0.139	0.48	0.31	0.162	0.41	0.7	0.117	0.55	0.35	-0.073	0.71	0.24	0.325	0.09
84	1984	0	0.13	0.08	0.67	0.19	0.103	0.59	0.22	0.035	0.86	0.62	-0.257	0.17	0.35	-0.165	0.38	0.14	0.296	0.11
85	2009		0.56			0.47			0.53			0.74			0.67			0.47		
85	2004	0.01	0.68	-0.526	0.01	0.55	-0.478	0.02	0.55	-0.477	0.02	0.8	-0.474	0.02	0.77	-0.576	0	0.46	-0.285	0.19
85	1998	0	0.7	-0.065	0.75	0.7	-0.169	0.41	0.67	-0.096	0.64	0.86	0.008	0.97	0.71	-0.182	0.37	0.46	0.168	0.41
85	1994	0.02	0.61	-0.501	0	0.5	-0.334	0.07	0.51	-0.224	0.23	0.79	-0.505	0	0.62	-0.444	0.01	0.35	-0.272	0.14
85	1988	0.01	0.6	-0.216	0.2	0.56	-0.231	0.17	0.64	-0.227	0.18	0.86	-0.023	0.89	0.72	-0.22	0.19	0.49	0.074	0.66
85	1984	0.05	0.47	0.082	0.62	0.5	0.093	0.57	0.59	0	1	0.86	0.014	0.93	0.74	0.017	0.92	0.21	0.072	0.66
86	2009		0.59			0.58			0.69			0.7			0.66			0.3		
86	2004	0.16	0.7	-0.143	0.54	0.65	-0.286	0.21	0.68	-0.347	0.12	0.83	-0.275	0.23	0.79	-0.349	0.12	0.24	-0.227	0.32

		i_h	ln(1+CI$_3$)			ln(1+CI$_4$)			ln(1+CI$_5$)			ln(1+CI$_6$)			ln(1+CI$_7$)			ln(1+CI$_8$)		
PEPs	inv	h	h	Partial corr		h	Partial corr		h	Partial corr		h	Partial corr		h	Partial corr		h	Partial corr	
		R^2	R^2	r	Sign	R^2	r	Sign	R^2	r	Sign	R^2	r	Sign	R^2	r	Sign	R^2	r	Sign
86	1998	0.26	0.75	-0.023	0.91	0.66	-0.141	0.51	0.65	-0.106	0.62	0.81	-0.316	0.13	0.84	-0.089	0.68	0.33	-0.009	0.97
86	1994	0.02	0.8	0.09	0.69	0.65	0.245	0.27	0.68	0.226	0.31	0.86	0.019	0.93	0.88	-0.112	0.62	0.61	0.536	0.01
86	1988	0.1	0.69	0.063	0.75	0.66	-0.041	0.84	0.61	0.207	0.29	0.77	-0.102	0.61	0.67	0.414	0.03	0.54	0.032	0.87
86	1984	0	0.38	-0.108	0.61	0.36	-0.192	0.36	0.58	-0.118	0.57	0.76	-0.006	0.98	0.72	-0.02	0.92	0.13	0.082	0.7
87	2009		0.44			0.47			0.57			0.75			0.63			0.33		
87	2004	0.26	0.97	-0.232	0.47	0.86	0.258	0.42	0.88	0.084	0.79	0.93	-0.15	0.64	0.87	0.043	0.9	0.48	-0.525	0.08
87	1998	0.25	0.71	-0.23	0.39	0.64	0.011	0.97	0.67	0.05	0.85	0.8	-0.096	0.72	0.81	-0.343	0.19	0.2	0.001	1
87	1994	0	0.7	-0.253	0.31	0.71	-0.342	0.17	0.79	-0.491	0.04	0.79	-0.194	0.44	0.86	-0.458	0.06	0.53	0.131	0.61
87	1988	0.39	0.84	0.235	0.31	0.83	0.182	0.43	0.78	0.223	0.33	0.82	0.009	0.97	0.79	0.05	0.83	0.69	0.026	0.91
87	1984	0.05	0.67	-0.029	0.89	0.67	-0.072	0.74	0.69	-0.227	0.3	0.79	-0.22	0.31	0.75	-0.21	0.34	0.18	0.287	0.18
88	2009		0.88			0.8			0.83			0.86			0.87			0.56		
88	2004	0.09	0.88	0.003	0.99	0.83	-0.335	0.22	0.88	-0.289	0.3	0.9	-0.505	0.05	0.93	-0.395	0.15	0.6	0.01	0.97
88	1998	0.43	0.79	-0.466	0.08	0.71	-0.245	0.38	0.71	-0.28	0.31	0.9	-0.265	0.34	0.87	-0.44	0.1	0.67	-0.351	0.2
88	1994	0.26	0.69	-0.313	0.22	0.67	-0.54	0.03	0.67	-0.564	0.02	0.85	-0.498	0.04	0.78	-0.332	0.19	0.4	-0.246	0.34
88	1988	0.18	0.77	-0.163	0.46	0.77	-0.176	0.42	0.8	-0.041	0.85	0.9	-0.239	0.27	0.81	-0.342	0.11	0.47	-0.121	0.58
88	1984	0.01	0.64	-0.231	0.29	0.52	-0.017	0.94	0.61	-0.15	0.49	0.79	-0.143	0.51	0.72	-0.664	0	0.4	0.368	0.08
89	2009		0.77			0.66			0.73			0.77			0.81			0.48		
89	2004	0.2	0.59	-0.168	0.42	0.44	-0.221	0.29	0.52	-0.186	0.37	0.77	-0.279	0.18	0.74	-0.297	0.15	0.28	-0.005	0.98
89	1998	0	0.42	-0.324	0.12	0.33	-0.171	0.43	0.3	-0.201	0.35	0.69	-0.049	0.82	0.61	-0.248	0.24	0.33	0.04	0.85
89	1994	0.09	0.47	-0.247	0.22	0.32	-0.201	0.32	0.36	-0.151	0.46	0.7	-0.175	0.39	0.58	-0.192	0.35	0.26	-0.016	0.94
89	1988	0.12	0.45	-0.264	0.18	0.37	-0.201	0.31	0.35	-0.249	0.21	0.61	-0.277	0.16	0.57	-0.299	0.13	0.4	-0.072	0.72
89	1984	0.01	0.26	0.161	0.46	0.36	0.286	0.19	0.45	0.143	0.52	0.59	-0.059	0.79	0.5	-0.025	0.91	0.27	0.234	0.28
90	2009		0.35			0.32			0.47			0.69			0.61			0.26		
90	2004	0.05	0.39	-0.49	0.05	0.16	-0.595	0.02	0.26	-0.501	0.05	0.83	-0.634	0.01	0.8	-0.563	0.02	0.28	-0.385	0.14
90	1998	0.03	0.63	-0.207	0.37	0.44	-0.417	0.06	0.57	-0.493	0.02	0.81	-0.391	0.08	0.8	-0.159	0.49	0.37	0	1
90	1994	0	0.67	0.25	0.35	0.54	0.193	0.47	0.62	0.129	0.63	0.82	0.27	0.31	0.82	0.366	0.16	0.47	0.292	0.27
90	1988	0.02	0.81	0.002	0.99	0.64	0.036	0.89	0.65	-0.056	0.83	0.91	-0.122	0.64	0.88	-0.207	0.43	0.61	-0.019	0.94
90	1984	0.45	0.67	-0.315	0.12	0.7	-0.016	0.94	0.74	0.106	0.61	0.88	-0.004	0.99	0.82	-0.193	0.35	0.39	0.106	0.6
91	2009		0.26			0.45			0.47			0.65			0.35			0.06		
91	2004	0.15	0.52	-0.282	0.31	0.54	0.035	0.9	0.61	-0.09	0.75	0.85	-0.25	0.37	0.72	-0.332	0.23	0.11	0.383	0.16
91	1998	0.23	0.46	0.397	0.06	0.46	0.169	0.44	0.54	0.043	0.85	0.76	0.09	0.68	0.6	0.316	0.14	0.2	0.373	0.08
91	1994	0.01	0.24	-0.096	0.69	0.39	0.036	0.88	0.51	0.114	0.63	0.74	0.317	0.17	0.52	0.155	0.51	0.08	0.058	0.81
91	1988	0.31	0.23	-0.388	0.15	0.17	-0.408	0.13	0.3	-0.287	0.3	0.55	-0.31	0.26	0.44	-0.63	0.01	0.16	-0.01	0.97
91	1984	0.01	0.57	0.137	0.6	0.6	-0.336	0.19	0.6	-0.457	0.07	0.6	0.31	0.23	0.44	0.364	0.15	0.14	0.21	0.42

		i_h	$\ln(1+CI_3)$			$\ln(1+CI_4)$			$\ln(1+CI_5)$			$\ln(1+CI_6)$			$\ln(1+CI_7)$			$\ln(1+CI_8)$		
PEPs	**inv**	**h**	**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**	
		R^2	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**
92	2009		0.45			0.39			0.49			0.71			0.55			0.15		
92	2004	0.01	0.35	0.187	0.39	0.29	0.047	0.83	0.36	0.102	0.64	0.69	0.22	0.31	0.54	0.235	0.28	0	0.113	0.61
92	1998	0.16	0.61	-0.25	0.35	0.56	-0.305	0.25	0.65	-0.175	0.52	0.84	-0.505	0.05	0.78	-0.29	0.28	0.06	-0.225	0.4
92	1994	0.05	0.6	0.015	0.94	0.59	0.013	0.95	0.67	-0.093	0.65	0.74	0.083	0.69	0.69	0.045	0.83	0.19	-0.294	0.15
92	1988	0	0.54	-0.242	0.22	0.58	-0.15	0.45	0.66	-0.267	0.17	0.79	-0.104	0.6	0.68	-0.429	0.02	0.13	0.121	0.54
92	1984	0	0.42	-0.024	0.91	0.33	-0.041	0.84	0.41	-0.059	0.77	0.69	0.008	0.97	0.43	0.02	0.92	0.1	-0.036	0.86
93	2009		0.51			0.56			0.65			0.78			0.64			0.43		
93	2004	0.02	0.47	0.157	0.61	0.67	-0.246	0.42	0.76	-0.127	0.68	0.96	0.06	0.84	0.72	0.47	0.11	0.27	-0.502	0.08
93	1998	0.02	0.38	0.072	0.83	0.69	0.142	0.68	0.88	0.328	0.33	0.92	-0.265	0.43	0.71	-0.018	0.96	0.24	0.319	0.34
93	1994	0.09	0.64	-0.143	0.63	0.82	-0.258	0.37	0.89	-0.45	0.11	0.96	-0.362	0.2	0.78	-0.324	0.26	0.36	-0.281	0.33
93	1988	0.09	0.55	-0.41	0.16	0.69	-0.238	0.43	0.81	-0.3	0.32	0.88	-0.559	0.05	0.62	-0.489	0.09	0.43	-0.253	0.4
93	1984	0.19	0.86	-0.526	0.03	0.79	-0.528	0.03	0.81	-0.559	0.02	0.95	-0.538	0.03	0.87	-0.621	0.01	0.6	0.105	0.69
94	2009		0.38			0.31			0.42			0.77			0.54			0.21		
94	2004	0.04	0.49	-0.203	0.35	0.42	-0.294	0.17	0.52	-0.246	0.26	0.87	-0.324	0.13	0.69	-0.101	0.65	0.24	-0.26	0.23
94	1998	0.22	0.51	0.128	0.66	0.52	0.143	0.62	0.6	0.17	0.56	0.86	-0.377	0.18	0.58	-0.02	0.95	0.22	-0.045	0.88
94	1994	0	0.53	-0.166	0.43	0.58	-0.335	0.1	0.64	-0.311	0.13	0.88	-0.056	0.79	0.7	0.007	0.97	0.28	-0.297	0.15
94	1988	0.11	0.72	0.018	0.93	0.65	0.037	0.86	0.73	0.029	0.89	0.92	-0.102	0.63	0.83	-0.019	0.93	0.53	0.126	0.55
94	1984	0.01	0.73	-0.16	0.44	0.54	-0.029	0.89	0.73	-0.018	0.93	0.84	-0.177	0.39	0.81	-0.373	0.06	0.38	0.101	0.62
95	2009		0.47			0.43			0.5			0.62			0.5			0.21		
95	2004	0	0.37	-0.096	0.67	0.58	-0.308	0.16	0.65	-0.296	0.18	0.78	-0.108	0.63	0.54	-0.205	0.36	0.26	0.106	0.64
95	1998	0.08	0.25	-0.067	0.83	0.43	-0.266	0.38	0.44	-0.178	0.56	0.8	0.065	0.83	0.49	0.058	0.85	0.32	0.23	0.45
95	1994	0.35	0.6	0.304	0.25	0.76	0.437	0.09	0.79	0.391	0.13	0.86	0.286	0.28	0.71	0.304	0.25	0.53	0.147	0.59
95	1988	0.01	0.54	-0.113	0.61	0.71	0.017	0.94	0.74	-0.01	0.96	0.84	-0.047	0.83	0.63	-0.125	0.57	0.43	0.269	0.21
95	1984	0.15	0.41	0.134	0.54	0.7	0.167	0.45	0.75	0.133	0.54	0.81	-0.173	0.43	0.62	0.101	0.65	0.16	0.118	0.59
96	2009		0.51			0.48			0.58			0.74			0.65			0.38		
96	2004	0	0.33	0.172	0.61	0.39	0.162	0.63	0.55	0.121	0.72	0.76	0.323	0.33	0.55	0.082	0.81	0.44	0.447	0.17
96	1998	0.17	0.54	-0.066	0.84	0.63	-0.068	0.83	0.73	-0.147	0.65	0.83	-0.28	0.38	0.7	-0.229	0.47	0.45	0.232	0.47
96	1994	0.18	0.36	-0.532	0.06	0.44	-0.461	0.11	0.54	-0.368	0.22	0.81	-0.564	0.04	0.48	-0.57	0.04	0.34	-0.361	0.22
96	1988	0.4	0.74	-0.076	0.73	0.67	-0.404	0.06	0.74	-0.346	0.11	0.81	-0.448	0.03	0.83	-0.121	0.58	0.52	-0.067	0.76
96	1984	0.36	0.82	0.242	0.28	0.76	-0.108	0.63	0.76	-0.182	0.42	0.9	-0.086	0.7	0.86	0.031	0.89	0.62	0.21	0.35
201_1	2009		0.56			0.43			0.7			0.83			0.83			0.17		
201_2	2009		0.63			0.56			0.71			0.87			0.76			0.42		
201_1	2004	0.18	0.55	-0.333	0.05	0.58	-0.183	0.29	0.65	-0.207	0.23	0.83	-0.186	0.28	0.56	-0.174	0.32	0.79	0.188	0.28
201_2	2004	0.04	0.48	-0.493	0.01	0.59	-0.462	0.02	0.62	-0.469	0.02	0.84	-0.488	0.02	0.54	-0.371	0.07	0.82	-0.203	0.34

		i_h	$\ln(1+CI_3)$			$\ln(1+CI_4)$			$\ln(1+CI_5)$			$\ln(1+CI_6)$			$\ln(1+CI_7)$			$\ln(1+CI_8)$		
PEPs	**inv**	**h**	**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**	
		R^2	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**
201_1	1998	0.06	0.31	-0.49	0	0.36	-0.474	0	0.45	-0.526	0	0.86	-0.414	0.01	0.37	-0.471	0	0.72	-0.1	0.53
201_2	1998	0.01	0.48	-0.572	0	0.52	-0.541	0	0.55	-0.544	0	0.89	-0.376	0.04	0.55	-0.546	0	0.78	-0.161	0.39
201_1	1994	0.25	0.47	-0.204	0.15	0.43	-0.134	0.35	0.52	-0.264	0.06	0.8	-0.42	0	0.48	-0.133	0.35	0.46	0.013	0.93
201_2	1994	0.12	0.36	-0.334	0.05	0.26	-0.327	0.06	0.27	-0.367	0.03	0.78	-0.462	0.01	0.42	-0.29	0.09	0.53	-0.12	0.49
206_1	2009		0.68			0.5			0.71			0.77			0.74			0.4		
206_2	2009		0.83			0.83			0.89			0.92			0.88			0.41		
206_1	2004	0.16	0.45	-0.411	0.07	0.43	-0.379	0.1	0.52	-0.405	0.08	0.67	-0.318	0.17	0.53	-0.409	0.07	0.33	-0.159	0.5
206_2	2004	0.64	0.83	-0.491	0.01	0.78	-0.494	0.01	0.83	-0.527	0	0.89	-0.434	0.02	0.77	-0.471	0.01	0.73	-0.157	0.43
206_1	1998	0.07	0.58	-0.631	0	0.66	-0.241	0.26	0.78	-0.326	0.12	0.85	-0.177	0.41	0.74	-0.345	0.1	0.56	0.078	0.72
206_2	1998	0.02	0.52	-0.301	0.11	0.42	-0.452	0.01	0.52	-0.484	0.01	0.81	-0.296	0.11	0.5	-0.003	0.99	0.27	0.326	0.08
Average		0.12	0.52	-0.148	0.43	0.53	-0.142	0.42	0.61	-0.159	0.41	0.8	-0.186	0.4	0.65	-0.19	0.37	0.33	0.016	0.47
Share of significant cases					9.20%			11.50%			14.90%			18.40%			14.90%			0.00%

(g). The influence of distance dependent competition indices combined with selection method SB 60, on periodic mean annual tree height increment.

		i_h	$\ln(1+CI_3)$			$\ln(1+CI_4)$			$\ln(1+CI_5)$			$\ln(1+CI_6)$			$\ln(1+CI_7)$			$\ln(1+CI_8)$		
PEPs	**inv**	**h**	**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**	
		R^2	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**
81	2009																			
81	2004		0.14			0.15			0.31			0.8			0.31			0.11		
81	1998	0.28	0.12	-0.256	0.31	0.16	-0.182	0.47	0.35	-0.254	0.31	0.81	-0.228	0.36	0.31	-0.321	0.19	0.32	-0.272	0.27
81	1994	0	0.14	0.365	0.18	0.06	0.114	0.69	0.14	-0.018	0.95	0.7	0.068	0.81	0.12	0.081	0.78	0.15	0.398	0.14
81	1988	0	0.45	-0.226	0.35	0.43	-0.421	0.07	0.55	-0.352	0.14	0.88	-0.315	0.19	0.51	-0.244	0.31	0.36	-0.195	0.42
81	1984	0.01	0.07	-0.209	0.36	0.08	-0.2	0.38	0.23	-0.15	0.52	0.72	-0.01	0.97	0.17	-0.11	0.63	0.06	0.176	0.45
82	2009		0.57			0.57			0.66			0.87			0.67			0.54		
82	2004																			
82	1998	0.64	0.23	0.086	0.84	0.53	0.133	0.75	0.63	0.066	0.88	0.93	0.14	0.74	0.58	0.081	0.85	0.35	-0.098	0.82
82	1994	0.13	0.04	-0.017	0.95	0.16	-0.106	0.68	0.4	-0.099	0.7	0.74	-0.218	0.4	0.37	-0.1	0.7	0.04	0.013	0.96
82	1988	0.13	0.34	-0.496	0.02	0.39	-0.465	0.03	0.55	-0.481	0.03	0.84	-0.231	0.31	0.5	-0.517	0.02	0.16	0.179	0.44
82	1984	0.28	0.46	0.03	0.89	0.51	-0.035	0.87	0.64	-0.13	0.55	0.9	-0.251	0.25	0.63	-0.153	0.48	0.27	0.586	0
83	2009		0.33			0.03			0.15			0.64			0.24			0.33		
83	2004	0.04	0.25	-0.094	0.63	0.29	-0.099	0.61	0.43	0.046	0.81	0.89	0.061	0.75	0.4	0.14	0.47	0.14	-0.145	0.45
83	1998	0.03	0.37	-0.382	0.04	0.38	-0.413	0.02	0.48	-0.446	0.01	0.89	-0.236	0.21	0.49	-0.471	0.01	0.27	0.146	0.44
83	1994	0	0.59	-0.315	0.13	0.67	-0.548	0.01	0.75	-0.556	0	0.93	-0.473	0.02	0.75	-0.459	0.02	0.43	0.22	0.3
83	1988	0	0.35	-0.175	0.39	0.46	-0.037	0.86	0.56	-0.106	0.61	0.93	-0.193	0.34	0.53	-0.245	0.23	0.39	0.234	0.25
83	1984	0.06	0.27	-0.367	0.06	0.42	-0.41	0.03	0.53	-0.377	0.05	0.92	-0.181	0.37	0.5	-0.348	0.08	0.37	0.252	0.21
84	2009		0.42			0.18			0.37			0.8			0.42			0.42		
84	2004																			
84	1998	0.06	0.4	-0.206	0.22	0.42	-0.322	0.05	0.51	-0.303	0.07	0.89	-0.286	0.09	0.5	-0.216	0.2	0.38	-0.002	0.99
84	1994	0.02	0.3	-0.387	0.05	0.27	-0.341	0.09	0.38	-0.287	0.16	0.87	-0.519	0.01	0.42	-0.302	0.13	0.32	-0.239	0.24
84	1988	0.07	0.26	-0.315	0.1	0.33	-0.334	0.08	0.4	-0.354	0.06	0.89	-0.035	0.86	0.37	-0.361	0.06	0.49	0.422	0.03
84	1984	0	0.17	-0.215	0.25	0.26	-0.293	0.12	0.33	-0.342	0.06	0.8	-0.433	0.02	0.35	-0.399	0.03	0.51	0.296	0.11
85	2009		0.33			0.19			0.34			0.75			0.39			0.59		
85	2004	0.01	0.62	-0.277	0.2	0.45	-0.327	0.13	0.45	-0.206	0.35	0.89	-0.459	0.03	0.5	-0.144	0.51	0.59	-0.331	0.12
85	1998	0	0.55	-0.347	0.08	0.45	-0.329	0.1	0.44	-0.313	0.12	0.89	-0.18	0.38	0.44	-0.336	0.09	0.5	-0.184	0.37
85	1994	0.02	0.5	-0.413	0.02	0.44	-0.42	0.02	0.5	-0.315	0.08	0.88	-0.167	0.37	0.48	-0.253	0.17	0.47	0.127	0.49
85	1988	0.01	0.45	-0.335	0.04	0.49	-0.28	0.09	0.61	-0.207	0.22	0.92	-0.17	0.31	0.55	-0.214	0.2	0.41	-0.022	0.9
85	1984	0.05	0.43	-0.048	0.77	0.41	-0.101	0.54	0.5	-0.103	0.53	0.91	-0.022	0.89	0.48	-0.077	0.64	0.36	0.075	0.64
86	2009		0.42			0.38			0.53			0.74			0.57			0.38		
86	2004	0.16	0.56	0.085	0.71	0.51	0.082	0.72	0.64	-0.05	0.83	0.84	-0.042	0.86	0.61	-0.084	0.72	0.29	-0.03	0.9

		i_h	$ln(1+CI_3)$			$ln(1+CI_4)$			$ln(1+CI_5)$			$ln(1+CI_6)$			$ln(1+CI_7)$			$ln(1+CI_8)$		
PEPs	**inv**	**h**	**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**	
		R^2	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**
86	1998	0.26	0.65	-0.091	0.67	0.59	-0.247	0.24	0.7	-0.188	0.38	0.87	-0.45	0.03	0.64	-0.075	0.73	0.48	-0.073	0.74
86	1994	0.02	0.58	-0.611	0	0.49	-0.639	0	0.66	-0.668	0	0.9	-0.382	0.08	0.65	-0.628	0	0.74	0.443	0.04
86	1988	0.1	0.54	-0.136	0.49	0.48	-0.157	0.43	0.67	0.206	0.29	0.89	-0.222	0.26	0.62	0.394	0.04	0.68	-0.021	0.91
86	1984	0	0.66	-0.269	0.19	0.52	-0.304	0.14	0.71	-0.197	0.35	0.89	-0.22	0.29	0.75	-0.099	0.64	0.59	0.004	0.99
87	2009		0.6			0.48			0.64			0.85			0.69			0.5		
87	2004	0.26	0.73	0.304	0.34	0.56	0.344	0.27	0.59	0.269	0.4	0.93	0.142	0.66	0.62	0.17	0.6	0.36	-0.526	0.08
87	1998	0.25	0.63	-0.322	0.22	0.63	-0.218	0.42	0.68	-0.265	0.32	0.91	-0.207	0.44	0.65	-0.355	0.18	0.54	0.004	0.99
87	1994	0	0.57	-0.299	0.23	0.41	-0.259	0.3	0.7	-0.372	0.13	0.79	-0.132	0.6	0.77	-0.483	0.04	0.52	0.059	0.82
87	1988	0.39	0.75	0.018	0.94	0.63	-0.107	0.65	0.67	-0.149	0.52	0.86	-0.063	0.79	0.66	-0.112	0.63	0.63	0.187	0.42
87	1984	0.05	0.71	-0.555	0.01	0.66	-0.535	0.01	0.68	-0.466	0.02	0.83	-0.308	0.15	0.64	-0.416	0.05	0.59	0.243	0.26
88	2009		0.8			0.65			0.79			0.85			0.81			0.45		
88	2004	0.09	0.77	-0.647	0.01	0.68	-0.601	0.02	0.8	-0.527	0.04	0.9	-0.574	0.03	0.8	-0.479	0.07	0.45	-0.059	0.83
88	1998	0.43	0.86	-0.147	0.6	0.86	-0.361	0.19	0.86	-0.209	0.46	0.94	-0.243	0.38	0.85	0.01	0.97	0.69	0.235	0.4
88	1994	0.26	0.7	-0.033	0.9	0.62	-0.117	0.65	0.67	-0.053	0.84	0.91	-0.393	0.12	0.69	0.034	0.9	0.48	-0.048	0.85
88	1988	0.18	0.67	-0.466	0.03	0.53	-0.548	0.01	0.61	-0.482	0.02	0.92	-0.594	0	0.61	-0.387	0.07	0.34	-0.303	0.16
88	1984	0.01	0.23	-0.7	0	0.11	-0.698	0	0.19	-0.668	0	0.8	-0.581	0	0.18	-0.642	0	0.4	0.291	0.18
89	2009		0.67			0.36			0.53			0.8			0.63			0.62		
89	2004	0.2	0.65	-0.404	0.04	0.52	-0.484	0.01	0.65	-0.495	0.01	0.86	-0.329	0.11	0.72	-0.419	0.04	0.5	0.299	0.15
89	1998	0	0.65	-0.044	0.84	0.5	-0.127	0.55	0.51	-0.071	0.74	0.85	-0.11	0.61	0.52	0.019	0.93	0.7	0.112	0.6
89	1994	0.09	0.55	-0.354	0.08	0.43	-0.361	0.07	0.55	-0.277	0.17	0.86	-0.258	0.2	0.61	-0.206	0.31	0.67	-0.146	0.48
89	1988	0.12	0.54	-0.168	0.4	0.43	-0.216	0.28	0.52	-0.201	0.31	0.83	-0.233	0.24	0.55	-0.174	0.39	0.72	0.333	0.09
89	1984	0.01	0.36	-0.106	0.63	0.27	-0.158	0.47	0.44	-0.232	0.29	0.82	0.199	0.36	0.5	-0.28	0.2	0.64	0.451	0.03
90	2009		0.46			0.24			0.45			0.76			0.54			0.35		
90	2004	0.05	0.44	-0.349	0.18	0.53	-0.369	0.16	0.71	-0.239	0.37	0.92	-0.499	0.05	0.66	-0.101	0.71	0.18	0.221	0.41
90	1998	0.03	0.47	-0.279	0.22	0.45	-0.328	0.15	0.67	-0.227	0.32	0.87	-0.3	0.19	0.65	-0.138	0.55	0.43	0.046	0.84
90	1994	0	0.64	0.285	0.29	0.57	0.175	0.52	0.7	0.183	0.5	0.89	0.288	0.28	0.7	0.266	0.32	0.37	0.527	0.04
90	1988	0.02	0.64	-0.026	0.92	0.76	-0.004	0.99	0.84	-0.052	0.84	0.92	-0.006	0.98	0.76	-0.127	0.63	0.42	-0.128	0.62
90	1984	0.45	0.66	-0.344	0.09	0.56	-0.227	0.27	0.69	-0.146	0.48	0.9	-0.097	0.64	0.72	-0.173	0.4	0.55	0.163	0.43
91	2009		0.13			0.22			0.26			0.84			0.23			0.25		
91	2004	0.15	0.33	-0.496	0.06	0.47	-0.448	0.09	0.62	-0.486	0.07	0.92	-0.172	0.54	0.6	-0.545	0.04	0.11	0.392	0.15
91	1998	0.23	0.22	0.223	0.31	0.32	0.194	0.38	0.45	0.162	0.46	0.83	0.279	0.2	0.41	0.156	0.48	0.11	0.342	0.11
91	1994	0.01	0.24	-0.134	0.57	0.37	0.048	0.84	0.55	0.176	0.46	0.83	0.269	0.25	0.57	0.102	0.67	0.03	-0.148	0.53
91	1988	0.31	0.12	-0.595	0.02	0.13	-0.708	0	0.28	-0.682	0.01	0.68	-0.42	0.12	0.32	-0.626	0.01	0.29	-0.269	0.33
91	1984	0.01	0.16	0.011	0.97	0.16	0.215	0.41	0.17	0.248	0.34	0.65	0.4	0.11	0.18	0.16	0.54	0.25	0.303	0.24

		i_h	$\ln(1+CI_3)$			$\ln(1+CI_4)$			$\ln(1+CI_5)$			$\ln(1+CI_6)$			$\ln(1+CI_7)$			$\ln(1+CI_8)$		
PEPs	**inv**	**h**	**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**	
		R^2	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**
92	2009		0.45			0.23			0.38			0.75			0.44			0.16		
92	2004	0.01	0.34	0.102	0.64	0.37	0.027	0.9	0.51	0.096	0.66	0.81	0.132	0.55	0.52	0.186	0.4	0	0.095	0.67
92	1998	0.16	0.58	-0.107	0.69	0.54	-0.176	0.51	0.71	-0.222	0.41	0.89	-0.406	0.12	0.71	-0.132	0.63	0.11	-0.207	0.44
92	1994	0.05	0.54	0.158	0.44	0.47	0.252	0.22	0.53	0.225	0.27	0.76	0.204	0.32	0.56	0.218	0.28	0.22	-0.157	0.44
92	1988	0	0.45	-0.472	0.01	0.34	-0.491	0.01	0.46	-0.486	0.01	0.78	-0.269	0.17	0.54	-0.529	0	0.07	0.017	0.93
92	1984	0	0.34	0.077	0.7	0.11	0.1	0.62	0.1	0.065	0.75	0.63	0.054	0.79	0.16	0.063	0.75	0.04	-0.024	0.9
93	2009		0.42			0.29			0.47			0.76			0.52			0.4		
93	2004	0.02	0.45	0.216	0.48	0.56	0.231	0.45	0.66	0.415	0.16	0.93	0.151	0.62	0.61	0.446	0.13	0.37	-0.796	0
93	1998	0.02	0.28	-0.225	0.51	0.53	-0.292	0.38	0.78	-0.411	0.21	0.91	-0.471	0.14	0.71	-0.395	0.23	0.27	0.227	0.5
93	1994	0.09	0.47	0.163	0.58	0.44	0.129	0.66	0.66	0.02	0.95	0.93	0.093	0.75	0.67	-0.006	0.98	0.55	0.102	0.73
93	1988	0.09	0.43	-0.179	0.56	0.42	-0.143	0.64	0.59	-0.323	0.28	0.95	-0.417	0.16	0.62	-0.306	0.31	0.68	0.391	0.19
93	1984	0.19	0.67	-0.561	0.02	0.52	-0.428	0.09	0.65	-0.462	0.06	0.95	-0.298	0.24	0.67	-0.529	0.03	0.64	-0.071	0.79
94	2009		0.53			0.33			0.5			0.84			0.52			0.35		
94	2004	0.04	0.52	-0.204	0.35	0.37	-0.206	0.35	0.44	-0.082	0.71	0.91	-0.344	0.11	0.49	0.007	0.98	0.27	-0.103	0.64
94	1998	0.22	0.44	0.056	0.85	0.25	-0.051	0.86	0.33	-0.109	0.71	0.92	-0.542	0.05	0.45	-0.112	0.7	0.3	0.042	0.89
94	1994	0	0.53	0.321	0.12	0.42	0.276	0.18	0.55	0.321	0.12	0.93	0.273	0.19	0.65	0.436	0.03	0.43	0.068	0.75
94	1988	0.11	0.65	-0.073	0.73	0.51	0.05	0.81	0.61	0.062	0.77	0.94	-0.242	0.24	0.73	-0.094	0.65	0.5	0.022	0.92
94	1984	0.01	0.38	-0.211	0.3	0.29	-0.207	0.31	0.44	-0.269	0.18	0.8	-0.231	0.26	0.48	-0.305	0.13	0.18	0.153	0.46
95	2009		0.35			0.19			0.31			0.67			0.32			0.39		
95	2004	0	0.21	-0.223	0.32	0.23	-0.401	0.06	0.37	-0.44	0.04	0.88	-0.526	0.01	0.34	-0.364	0.1	0.32	0.15	0.51
95	1998	0.08	0.08	-0.018	0.95	0.23	-0.106	0.73	0.41	0.054	0.86	0.92	-0.003	0.99	0.31	0.134	0.66	0.45	0.343	0.25
95	1994	0.35	0.37	0.118	0.66	0.48	0.025	0.93	0.66	0.068	0.8	0.88	0.278	0.3	0.56	0.177	0.51	0.08	-0.217	0.42
95	1988	0.01	0.24	-0.156	0.48	0.36	0.012	0.96	0.5	-0.013	0.95	0.9	0.065	0.77	0.34	-0.175	0.43	0.36	0.126	0.57
95	1984	0.15	0.34	0.073	0.74	0.41	0.018	0.94	0.54	0.004	0.98	0.89	-0.09	0.68	0.5	0.061	0.78	0.24	0.043	0.85
96	2009		0.35			0.4			0.56			0.84			0.57			0.33		
96	2004	0	0.04	-0.002	1	0.01	0.038	0.91	0.12	-0.038	0.91	0.84	0.352	0.29	0.18	-0.164	0.63	0.44	0.293	0.38
96	1998	0.17	0.22	-0.371	0.24	0.15	-0.435	0.16	0.34	-0.455	0.14	0.82	-0.315	0.32	0.41	-0.43	0.16	0.34	-0.132	0.68
96	1994	0.18	0.13	-0.502	0.08	0.06	-0.46	0.11	0.15	-0.373	0.21	0.79	-0.351	0.24	0.18	-0.374	0.21	0.22	-0.113	0.71
96	1988	0.4	0.5	-0.184	0.4	0.32	-0.302	0.16	0.38	-0.255	0.24	0.85	-0.355	0.1	0.35	-0.139	0.53	0.63	-0.116	0.6
96	1984	0.36	0.55	-0.35	0.11	0.39	-0.413	0.06	0.51	-0.416	0.05	0.92	-0.341	0.12	0.48	-0.38	0.08	0.67	0.067	0.77
201_1	2009		0.58			0.43			0.66			0.84			0.7			0.19		
201_2	2009		0.5			0.43			0.62			0.88			0.6			0.36		
201_1	2004	0.18	0.33	-0.385	0.02	0.23	-0.194	0.26	0.29	-0.208	0.23	0.85	-0.144	0.41	0.32	-0.21	0.23	0.72	0.352	0.04
201_2	2004	0.04	0.21	-0.443	0.03	0.26	-0.414	0.04	0.34	-0.435	0.03	0.86	-0.503	0.01	0.3	-0.304	0.15	0.46	0.137	0.52

		i_h	$\ln(1+CI_3)$			$\ln(1+CI_4)$			$\ln(1+CI_5)$			$\ln(1+CI_6)$			$\ln(1+CI_7)$			$\ln(1+CI_8)$		
PEPs	**inv**	**h**	**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**	
		R^2	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**
201_1	1998	0.06	0.09	-0.479	0	0.05	-0.451	0	0.1	-0.441	0	0.85	-0.39	0.01	0.1	-0.457	0	0.44	-0.142	0.38
201_2	1998	0.01	0.24	-0.559	0	0.16	-0.575	0	0.25	-0.568	0	0.89	-0.377	0.04	0.25	-0.517	0	0.43	0.024	0.9
201_1	1994	0.25	0.27	-0.213	0.13	0.03	-0.121	0.4	0.08	-0.187	0.19	0.78	-0.443	0	0.23	-0.13	0.36	0.07	0.04	0.78
201_2	1994	0.12	0.14	-0.357	0.04	0	-0.308	0.07	0.01	-0.326	0.06	0.75	-0.451	0.01	0.14	-0.32	0.06	0.19	-0.171	0.33
206_1	2009		0.6			0.27			0.49			0.75			0.64			0.51		
206_2	2009		0.79			0.61			0.75			0.89			0.77			0.47		
206_1	2004	0.16	0.24	-0.431	0.06	0.22	-0.388	0.09	0.31	-0.411	0.07	0.57	-0.365	0.11	0.31	-0.431	0.06	0.04	-0.316	0.17
206_2	2004	0.64	0.63	-0.498	0.01	0.34	-0.426	0.03	0.51	-0.454	0.02	0.87	-0.434	0.02	0.49	-0.487	0.01	0.45	-0.282	0.15
206_1	1998	0.07	0.42	-0.6	0	0.14	-0.361	0.08	0.45	-0.461	0.02	0.76	-0.137	0.52	0.46	-0.263	0.21	0.09	0.119	0.58
206_2	1998	0.02	0.27	-0.393	0.03	0.1	-0.434	0.02	0.18	-0.424	0.02	0.7	-0.398	0.03	0.21	-0.198	0.29	0.03	0.028	0.88
Average		0.12	0.43	-0.209	0.35	0.37	-0.221	0.33	0.49	-0.211	0.34	0.84	-0.194	0.32	0.5	-0.187	0.35	0.37	0.052	0.49
Share of significant cases					24.10%			20.70%			20.70%			20.70%			18.40%			1.10%

h). The influence of distance dependent competition indices combined with selection method HWCW 60, on periodic mean annual tree height increment.

		i_h	$\ln(1+CI_3)$			$\ln(1+CI_4)$			$\ln(1+CI_5)$			$\ln(1+CI_6)$			$\ln(1+CI_7)$			$\ln(1+CI_8)$		
PEPs	**inv**	**h**	**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**	
		R^2	**R^2**	**r**	**Sign**	**R^2**	**r**	**Sign**	**R^2**	**R^2**	**Sign**	**R^2**	**r**	**Sign**	**R^2**	**r**	**Sign**	**R^2**	**r**	**Sign**
81	2009																			
81	2004		0.33			0.39			0.32			0.66			0.41			0.29		
81	1998	0.28	0.12	0.053	0.83	0.31	-0.293	0.24	0.35	-0.312	0.21	0.46	-0.209	0.41	0.19	-0.019	0.94	0.12	0.076	0.77
81	1994	0	0.51	0.614	0.01	0.54	0.48	0.07	0.5	0.27	0.33	0.6	0.247	0.38	0.46	0.54	0.04	0.46	0.479	0.07
81	1988	0	0.61	0.09	0.71	0.6	-0.101	0.68	0.59	-0.013	0.96	0.77	-0.299	0.21	0.67	-0.094	0.7	0.44	-0.103	0.67
81	1984	0.01	0.33	-0.384	0.09	0.48	-0.615	0	0.42	-0.576	0.01	0.55	-0.42	0.06	0.36	-0.407	0.07	0.23	-0.405	0.07
82	2009		0.54			0.62			0.64			0.71			0.61			0.31		
82	2004																			
82	1998	0.64	0.06	-0.259	0.54	0.66	0.43	0.29	0.57	0.471	0.24	0.77	-0.233	0.58	0.23	-0.371	0.37	0.01	-0.652	0.08
82	1994	0.13	0.21	-0.027	0.92	0.28	-0.233	0.37	0.29	-0.174	0.5	0.38	-0.058	0.82	0.31	-0.018	0.95	0.07	0.192	0.46
82	1988	0.13	0.31	-0.316	0.16	0.09	-0.251	0.27	0.14	-0.255	0.26	0.71	-0.182	0.43	0.5	-0.433	0.05	0.37	-0.018	0.94
82	1984	0.28	0.34	-0.281	0.19	0.12	-0.121	0.58	0.05	-0.117	0.6	0.75	-0.401	0.06	0.53	-0.395	0.06	0.26	-0.081	0.71
83	2009		0.51			0.38			0.39			0.52			0.51			0.41		
83	2004	0.04	0.42	-0.325	0.08	0.41	-0.094	0.63	0.33	-0.008	0.97	0.61	-0.151	0.43	0.56	-0.304	0.11	0.4	-0.348	0.06
83	1998	0.03	0.3	-0.147	0.44	0.18	0.17	0.37	0.11	0.235	0.21	0.5	-0.171	0.37	0.41	-0.264	0.16	0.16	-0.07	0.71
83	1994	0	0.41	-0.013	0.95	0.6	-0.165	0.44	0.65	-0.231	0.28	0.73	-0.212	0.32	0.61	-0.155	0.47	0.3	0.183	0.39
83	1988	0	0.49	0.325	0.11	0.42	-0.095	0.64	0.36	-0.139	0.5	0.74	-0.081	0.7	0.61	0.149	0.47	0.49	0.471	0.02
83	1984	0.06	0.11	0.241	0.23	0.24	-0.075	0.71	0.24	-0.084	0.68	0.4	0.172	0.39	0.21	0.215	0.28	0.17	0.295	0.14
84	2009		0.5			0.58			0.56			0.63			0.55			0.38		
84	2004																			
84	1998	0.06	0.19	-0.192	0.26	0.22	-0.097	0.57	0.21	-0.085	0.62	0.42	-0.309	0.06	0.25	-0.256	0.13	0.13	-0.238	0.16
84	1994	0.02	0.17	-0.058	0.78	0.17	-0.104	0.61	0.16	-0.1	0.63	0.38	-0.344	0.09	0.22	-0.151	0.46	0.11	0.063	0.76
84	1988	0.07	0.05	0.065	0.74	0	0.123	0.53	0	0.067	0.73	0.21	0.167	0.39	0.09	0.074	0.71	0.13	0.101	0.61
84	1984	0	0.01	0.011	0.95	0.03	0.02	0.92	0.03	0.04	0.83	0.23	-0.06	0.75	0.07	-0.065	0.73	0.03	0.071	0.71
85	2009		0.33			0.3			0.28			0.44			0.38			0.34		
85	2004	0.01	0.1	-0.096	0.66	0.1	-0.163	0.46	0.12	-0.1	0.65	0.28	-0.036	0.87	0.15	-0.138	0.53	0.17	0.159	0.47
85	1998	0	0.24	0.037	0.86	0.22	-0.023	0.91	0.14	-0.038	0.85	0.34	0.054	0.79	0.25	0.012	0.95	0.28	0.028	0.89
85	1994	0.02	0.16	0.193	0.3	0.23	0.067	0.72	0.17	0.035	0.85	0.29	0.031	0.87	0.14	0.19	0.31	0.17	0.209	0.26
85	1988	0.01	0.23	-0.239	0.15	0.34	-0.193	0.25	0.35	-0.127	0.45	0.52	-0.024	0.89	0.37	-0.218	0.2	0.25	-0.157	0.35
85	1984	0.05	0.38	0.059	0.72	0.36	-0.173	0.29	0.31	-0.234	0.15	0.61	-0.014	0.93	0.48	-0.028	0.86	0.33	0.213	0.19
86	2009		0.59			0.61			0.57			0.67			0.62			0.27		
86	2004	0.16	0.49	-0.409	0.07	0.47	-0.212	0.36	0.44	-0.109	0.64	0.59	-0.443	0.04	0.53	-0.481	0.03	0.26	-0.426	0.05

		i_h	$\ln(1+CI_3)$			$\ln(1+CI_4)$			$\ln(1+CI_5)$			$\ln(1+CI_6)$			$\ln(1+CI_7)$			$\ln(1+CI_8)$		
PEPs	**inv**	**h**	**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**	
		R^2	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	R^2	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**
86	1998	0.26	0.61	0.074	0.73	0.42	0.039	0.86	0.37	0.007	0.98	0.58	-0.083	0.7	0.58	-0.011	0.96	0.39	0.22	0.3
86	1994	0.02	0.55	0.243	0.28	0.48	0.322	0.14	0.45	0.323	0.14	0.65	0.207	0.36	0.6	0.183	0.41	0.44	0.281	0.21
86	1988	0.1	0.38	0.105	0.6	0.4	0.064	0.75	0.3	0.348	0.07	0.55	0.117	0.55	0.36	0.344	0.07	0.3	-0.014	0.94
86	1984	0	0.4	-0.1	0.64	0.4	-0.011	0.96	0.39	0.038	0.86	0.65	-0.007	0.97	0.56	0.025	0.91	0.25	-0.117	0.58
87	2009		0.4			0.47			0.5			0.56			0.49			0.32		
87	2004	0.26	0.84	0.24	0.45	0.61	-0.144	0.66	0.55	-0.131	0.69	0.77	-0.05	0.88	0.84	0.178	0.58	0.58	0.571	0.05
87	1998	0.25	0.49	0.136	0.62	0.27	0.294	0.27	0.2	0.229	0.39	0.5	0.119	0.66	0.53	0.067	0.81	0.55	0.437	0.09
87	1994	0	0.67	-0.356	0.15	0.52	-0.303	0.22	0.61	-0.295	0.23	0.68	-0.443	0.07	0.78	-0.517	0.03	0.57	-0.043	0.87
87	1988	0.39	0.65	0.177	0.44	0.46	0.105	0.65	0.45	0.122	0.6	0.67	0.328	0.15	0.68	0.121	0.6	0.56	0.269	0.24
87	1984	0.05	0.54	0.062	0.78	0.44	-0.304	0.16	0.42	-0.363	0.09	0.59	-0.116	0.6	0.57	0.031	0.89	0.28	0.25	0.25
88	2009		0.53			0.62			0.61			0.7			0.67			0.23		
88	2004	0.09	0.52	-0.082	0.77	0.66	0.103	0.72	0.63	0.211	0.45	0.68	-0.274	0.32	0.65	-0.172	0.54	0.29	-0.163	0.56
88	1998	0.43	0.57	-0.187	0.5	0.44	-0.173	0.54	0.36	-0.11	0.7	0.65	-0.433	0.11	0.58	-0.249	0.37	0.46	0.01	0.97
88	1994	0.26	0.51	-0.686	0	0.42	-0.312	0.22	0.33	-0.259	0.32	0.62	-0.459	0.06	0.57	-0.616	0.01	0.39	-0.543	0.02
88	1988	0.18	0.63	0.056	0.8	0.58	0.315	0.14	0.51	0.308	0.15	0.73	-0.01	0.96	0.63	-0.102	0.64	0.4	0.094	0.67
88	1984	0.01	0.41	-0.369	0.08	0.47	-0.368	0.08	0.44	-0.405	0.06	0.58	-0.349	0.1	0.4	-0.427	0.04	0.37	-0.072	0.75
89	2009		0.67			0.52			0.54			0.71			0.74			0.56		
89	2004	0.2	0.44	-0.338	0.1	0.38	-0.121	0.57	0.37	-0.029	0.89	0.43	-0.208	0.32	0.49	-0.265	0.2	0.29	-0.26	0.21
89	1998	0	0.1	-0.132	0.54	0.12	-0.354	0.09	0.12	-0.331	0.11	0.22	-0.148	0.49	0.12	-0.127	0.56	0.09	-0.018	0.93
89	1994	0.09	0.32	-0.041	0.84	0.19	-0.018	0.93	0.16	0.019	0.93	0.34	-0.039	0.85	0.34	-0.032	0.88	0.33	-0.014	0.94
89	1988	0.12	0.19	-0.178	0.37	0.17	-0.325	0.1	0.16	-0.304	0.12	0.27	-0.296	0.13	0.23	-0.218	0.27	0.25	-0.145	0.47
89	1984	0.01	0.24	0.163	0.46	0.11	-0.112	0.61	0.13	-0.106	0.63	0.26	-0.191	0.38	0.33	0.063	0.78	0.24	0.141	0.52
90	2009		0.33			0.29			0.42			0.38			0.44			0.21		
90	2004	0.05	0.1	-0.275	0.3	0.03	-0.159	0.56	0.03	-0.14	0.6	0.42	-0.218	0.42	0.29	-0.224	0.4	0.08	-0.368	0.16
90	1998	0.03	0.46	-0.421	0.06	0.52	-0.304	0.18	0.54	-0.261	0.25	0.57	-0.577	0.01	0.58	-0.429	0.05	0.32	-0.386	0.08
90	1994	0	0.53	0.46	0.07	0.44	-0.178	0.51	0.39	-0.334	0.21	0.59	0.191	0.48	0.66	0.533	0.03	0.46	0.323	0.22
90	1988	0.02	0.48	-0.096	0.71	0.44	-0.33	0.2	0.39	-0.459	0.06	0.56	-0.066	0.8	0.55	-0.186	0.48	0.44	0.205	0.43
90	1984	0.45	0.5	0.039	0.85	0.58	0.193	0.34	0.56	0.179	0.38	0.74	0.024	0.91	0.67	0.131	0.52	0.36	0.014	0.94
91	2009		0.14			0.3			0.29			0.4			0.23			0.07		
91	2004	0.15	0.28	-0.116	0.68	0.43	-0.367	0.18	0.48	-0.457	0.09	0.68	-0.113	0.69	0.47	-0.12	0.67	0.15	0.065	0.82
91	1998	0.23	0.11	0.185	0.4	0.31	0.125	0.57	0.34	0	1	0.44	-0.118	0.59	0.19	0.148	0.5	0.05	0.056	0.8
91	1994	0.01	0.16	0.037	0.88	0.25	0.041	0.86	0.31	-0.039	0.87	0.5	0.252	0.28	0.33	0.122	0.61	0.06	0.128	0.59
91	1988	0.31	0.01	-0.233	0.4	0.27	0.114	0.69	0.43	0.376	0.17	0.16	0.239	0.39	0.03	-0.256	0.36	0	0.006	0.98
91	1984	0.01	0.18	-0.382	0.13	0.39	-0.426	0.09	0.47	-0.404	0.11	0.46	-0.394	0.12	0.18	-0.312	0.22	0.16	-0.329	0.2

		i_h	$\ln(1+CI_3)$			$\ln(1+CI_4)$			$\ln(1+CI_5)$			$\ln(1+CI_6)$			$\ln(1+CI_7)$			$\ln(1+CI_8)$		
PEPs	**inv**	**h**	**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**	
		R^2	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	R^2	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**
92	2009		0.33			0.42			0.43			0.44			0.38			0.13		
92	2004	0.01	0.19	0.04	0.85	0.18	0.116	0.6	0.16	0.077	0.73	0.48	0.171	0.44	0.33	0.086	0.7	0.07	0.051	0.82
92	1998	0.16	0.37	-0.326	0.22	0.57	0.17	0.53	0.58	0.207	0.44	0.72	-0.436	0.09	0.55	-0.339	0.2	0.08	-0.499	0.05
92	1994	0.05	0.49	-0.119	0.56	0.56	-0.201	0.32	0.51	-0.232	0.25	0.59	-0.016	0.94	0.57	-0.102	0.62	0.25	-0.204	0.32
92	1988	0	0.55	-0.217	0.27	0.56	-0.349	0.07	0.45	-0.369	0.05	0.61	-0.268	0.17	0.59	-0.318	0.1	0.27	0.026	0.89
92	1984	0	0.36	-0.084	0.68	0.49	-0.1	0.62	0.49	-0.017	0.93	0.36	-0.109	0.59	0.28	-0.072	0.72	0.08	-0.081	0.69
93	2009		0.47			0.48			0.47			0.54			0.48			0.31		
93	2004	0.02	0.41	0.108	0.72	0.52	-0.214	0.48	0.52	-0.095	0.76	0.8	0.426	0.15	0.64	0.367	0.22	0.23	-0.028	0.93
93	1998	0.02	0.36	0.31	0.35	0.77	0.732	0.01	0.71	0.649	0.03	0.86	0.445	0.17	0.62	0.353	0.29	0.28	0.211	0.53
93	1994	0.09	0.68	0.027	0.93	0.6	-0.366	0.2	0.58	-0.36	0.21	0.89	-0.486	0.08	0.74	-0.128	0.66	0.63	0.023	0.94
93	1988	0.09	0.57	-0.266	0.38	0.23	-0.517	0.07	0.12	-0.546	0.05	0.59	-0.232	0.45	0.61	-0.378	0.2	0.43	-0.11	0.72
93	1984	0.19	0.83	-0.471	0.06	0.71	-0.464	0.06	0.63	-0.462	0.06	0.85	-0.507	0.04	0.84	-0.514	0.03	0.56	0.014	0.96
94	2009		0.16			0.28			0.37			0.47			0.28			0.06		
94	2004	0.04	0.25	-0.272	0.21	0.29	-0.188	0.39	0.27	-0.173	0.43	0.46	-0.354	0.1	0.33	-0.281	0.19	0.11	-0.19	0.38
94	1998	0.22	0.52	-0.04	0.89	0.62	0.171	0.56	0.61	0.155	0.6	0.71	0.108	0.71	0.54	-0.058	0.84	0.18	-0.07	0.81
94	1994	0	0.48	0.058	0.78	0.36	-0.124	0.55	0.36	-0.129	0.54	0.62	-0.066	0.76	0.55	0.109	0.6	0.2	-0.183	0.38
94	1988	0.11	0.33	0.011	0.96	0.44	0.033	0.87	0.43	0.102	0.63	0.75	0.179	0.39	0.47	0.056	0.79	0.1	0.107	0.61
94	1984	0.01	0.44	-0.237	0.24	0.55	-0.218	0.28	0.61	-0.222	0.27	0.78	0.192	0.35	0.62	-0.288	0.15	0.12	-0.157	0.44
95	2009		0.44			0.23			0.18			0.48			0.47			0.45		
95	2004	0	0.4	-0.216	0.33	0.22	-0.192	0.39	0.21	-0.165	0.46	0.51	-0.181	0.42	0.46	-0.197	0.38	0.29	-0.23	0.3
95	1998	0.08	0.02	-0.277	0.36	0.02	-0.207	0.5	0.03	-0.189	0.54	0.12	-0.202	0.51	0.04	-0.215	0.48	0.07	-0.324	0.28
95	1994	0.35	0.55	0.426	0.1	0.44	0.058	0.83	0.33	-0.041	0.88	0.64	0.423	0.1	0.58	0.41	0.11	0.4	0.685	0
95	1988	0.01	0.45	-0.205	0.35	0.33	-0.093	0.67	0.27	-0.068	0.76	0.51	-0.053	0.81	0.47	-0.172	0.43	0.44	0.066	0.77
95	1984	0.15	0.54	0.116	0.6	0.42	0.131	0.55	0.33	0.143	0.52	0.64	0.135	0.54	0.59	0.135	0.54	0.56	0.198	0.36
96	2009		0.41			0.53			0.56			0.58			0.52			0.3		
96	2004	0	0.46	-0.062	0.86	0.48	0.096	0.78	0.66	-0.057	0.87	0.65	0.089	0.79	0.57	-0.12	0.73	0.44	0.183	0.59
96	1998	0.17	0.57	-0.096	0.77	0.71	-0.184	0.57	0.71	-0.241	0.45	0.83	-0.101	0.76	0.71	-0.191	0.55	0.31	0.054	0.87
96	1994	0.18	0.49	-0.395	0.18	0.49	-0.323	0.28	0.53	-0.29	0.34	0.73	-0.192	0.53	0.57	-0.357	0.23	0.32	-0.177	0.56
96	1988	0.4	0.68	-0.347	0.1	0.57	-0.075	0.74	0.53	-0.039	0.86	0.71	-0.275	0.2	0.69	-0.419	0.05	0.5	-0.224	0.3
96	1984	0.36	0.73	-0.243	0.28	0.67	-0.01	0.97	0.61	0.099	0.66	0.74	-0.242	0.28	0.7	-0.254	0.25	0.54	-0.398	0.07
201_1	2009		0.67			0.65			0.7			0.81			0.82			0.31		
201_2	2009		0.56			0.49			0.53			0.79			0.69			0.58		
201_1	2004	0.18	0.59	-0.281	0.1	0.63	-0.285	0.1	0.56	-0.313	0.07	0.73	-0.34	0.05	0.63	-0.16	0.36	0.54	0.18	0.3
201_2	2004	0.04	0.32	-0.228	0.28	0.42	-0.418	0.04	0.37	-0.398	0.05	0.67	-0.42	0.04	0.39	-0.163	0.45	0.36	0.031	0.89

		i_h	$\ln(1+CI_3)$			$\ln(1+CI_4)$			$\ln(1+CI_5)$			$\ln(1+CI_6)$			$\ln(1+CI_7)$			$\ln(1+CI_8)$		
PEPs	**inv**	**h**	**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**		**h**	**Partial corr**	
		R^2	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	R^2	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**	R^2	**r**	**Sign**
201_1	1998	0.06	0.33	-0.474	0	0.39	-0.572	0	0.34	-0.491	0	0.68	-0.48	0	0.36	-0.44	0	0.4	-0.24	0.13
201_2	1998	0.01	0.33	-0.562	0	0.39	-0.503	0	0.39	-0.453	0.01	0.65	-0.495	0	0.34	-0.533	0	0.35	-0.466	0.01
201_1	1994	0.25	0.34	-0.323	0.02	0.27	-0.583	0	0.27	-0.637	0	0.54	-0.565	0	0.32	-0.239	0.09	0.24	-0.148	0.3
201_2	1994	0.12	0.08	-0.296	0.08	0.07	-0.299	0.08	0.07	-0.252	0.14	0.29	-0.396	0.02	0.08	-0.277	0.11	0.04	-0.237	0.17
206_1	2009		0.59			0.72			0.75			0.72			0.67			0.28		
206_2	2009		0.81			0.86			0.86			0.9			0.84			0.55		
206_1	2004	0.16	0.38	-0.422	0.06	0.55	-0.572	0.01	0.61	-0.614	0	0.52	-0.309	0.18	0.4	-0.385	0.09	0.22	-0.192	0.42
206_2	2004	0.64	0.66	-0.394	0.04	0.65	-0.381	0.05	0.5	-0.286	0.15	0.8	-0.424	0.03	0.64	-0.429	0.03	0.58	-0.208	0.3
206_1	1998	0.07	0.55	-0.588	0	0.65	-0.385	0.06	0.62	-0.477	0.02	0.78	-0.282	0.18	0.67	-0.317	0.13	0.56	0.049	0.82
206_2	1998	0.02	0.39	-0.533	0	0.36	-0.247	0.19	0.34	-0.084	0.66	0.6	-0.559	0	0.36	-0.459	0.01	0.27	-0.388	0.03
Average		0.12	0.4	-0.114	0.43	0.41	-0.125	0.42	0.4	-0.116	0.43	0.58	-0.137	0.4	0.47	-0.129	0.39	0.3	-0.026	0.47
Share of significant cases					8.00%			8.00%			6.90%			12.60%			12.60%			4.60%